Water Temperature Monitoring and Diadromous Fishes Temperature Concerns in the Connecticut River Upstream and Downstream of Vernon Dam, Vernon, Vermont Fall 2009 through Fall 2012

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Executive Summary

Connecticut River water temperature data is important for both state and federal fishery agencies in understanding the timing and subsequent effects or influence on critical life history events (e.g., migration and spawning) for fish species of management interest including those under restoration (American shad, *Alosa sapidissima*) or under recovery (shortnose sturgeon, *Acipenser brevirostrum*). Mechanisms for water temperature effects include fish energetics and physiology, as well as gonad development which are synchronized with preferred spawning temperatures. A pilot study to begin to obtain year-round data at locations from Wilder Dam, Wilder, Vermont (river mile 217), to the Turners Falls Dam's Cabot Station, Montague, Massachusetts (river mile 120), is presented from 15 digital temperature recording devices over a three year period, Fall 2009 through Fall 2012. This report focuses on temperature data upstream and downstream of Vernon Dam and its fishways in relation to a State of Vermont permitted thermal cooling water discharge by Vermont Yankee (VY) Nuclear Power Station, Vernon, Vermont. The VY thermal discharge is reported at up to 800 cubic feet a second and may reach temperatures of up to 100°F. There are other potential additive sources of temperature increase to the river in this area due to impounding of water by the adjacent Vernon Dam, Vernon, Vermont. Vermont Yankee is permitted to raise the entire river water temperature, after full mixing, below Vernon Dam, between 2° and 5°F, from May 16 through October 14 (Summer limits) and as much as 13.4°F, from October 15 and May 15 (Winter limits). Comparisons with VY water temperature monitoring data (three monitored sites in total, VY Station #7, #3, and fish ladder seasonally), and four proximally located U. S. Fish and Wildlife Service (USFWS) loggers, were determined statistically significant and highly correlated in all cases (Pearson Correlation Coefficient r values > 0.99, $P < 0.001$). USFWS data downstream of VY demonstrated a clear shift in increased temperature values distinguishable to the Cabot Station tailrace, downstream of the Turners Falls Dam, most clearly in the winter months. Diadromous fish restoration and population concerns, and information needs, particularly in the vicinity of the Vernon Dam fishways, are summarized below.

- Vermont Yankee thermal discharge is 0.45 miles upstream of Vernon Dam's upstream and downstream fishways and is a concern for potential impacts to migrating fishes of various lifestages.
- Upstream and downstream fish passage operation schedules as mandated by the Federal Energy Regulatory Commission do not coincide with Winter and Summer VY thermal limits – migratory fish passage dates span the period of April 1 through November 15 or, December 31 annually.
- Vernon Dam is located 142 river miles (rm) upstream from the river mouth. Fish attempting to migrate upstream past Vernon Dam must first pass the Holyoke Dam and Turners Falls Dam; two dams with a combined total of three fishways.
- There are numerous published studies, many from the Connecticut River, dealing with adult and juvenile American shad energetics, migration, survival, and physiology that suggest exposure to elevated water temperatures may negatively impact shad in a number of ways, potentially affecting (reducing) restoration targets for adult shad passage, abundance, and juvenile production upstream of Vernon Dam.
- Vermont Yankee studies on American shad have occurred but under previous, not current conditions, and also while the thermal discharge was operational.

- Examination of data on a population or other metric of response, to a permitted thermal increase, obtained while the thermal discharge in question remains in effect, does not allow a clear examination as to whether an impact(s) is occurring (i.e. no baseline on which to compare results).
- Timing, magnitude, duration of thermal exposure(s), and other related effects (e.g., energetics, physiology, movement, passage performance, rates of gonad development) of the VY thermal discharge on species such as American shad have yet to be scientifically examined in the context of current river conditions for both Vermont Yankee and its most recent thermal increase, and the Vernon Dam since structural and operational improvements.
- It is recommended that specialized studies (field and laboratory) be designed and conducted to conclusively determine whether there are in fact any detectable effects from the VY permitted discharge for species including American shad, as detailed in this report. A no thermal discharge (control) should be part of any study design.

Introduction

Fish species inhabiting the Connecticut River utilize water temperatures for important life history cues. As endothermic organisms, they are subject to temperature effects that influence behavior, physiology, movement, feeding, growth, maturation, spawning, egg and larval development, resilience to pathogens (stress), and survival (Moss 1970; Glebe and Leggett 1981; Stier and Crance 1985; Leonard et al. 1999; Zydlewski et al. 2003; Savoy et al. 2004; Greene et al. 2009; Castro-Santos and Letcher 2010; Marchall et al. 2011).

Water temperature monitoring can be accomplished with compact digital equipment that provides data at a sub-hourly frequency over a complete year. In Fall 2009, a pilot program to gather water temperature data throughout the Connecticut River basin was initiated as this information is important for fish populations and habitat management (ASMFC 2010). The Atlantic States Marine Fisheries Commission Amendment # 3 to the Interstate Fishery Management Plan for Shad and River Herring (American Shad Management) approved in 2010, identifies research needs that include: characterize tributary habitat quality and quantity for Alosine reintroductions and fish passage development; and, determine impacts of thermal power generation projects (e.g., nuclear and coal) that withdraw water for cooling (potential entrainment and impingement of fish) and discharge heated water (thermal barriers to migration, habitat degradation) on estuarine juvenile rearing and migration corridors (ASMFC 2010).

The goal of the study was to document river water temperature regimes on a full year basis, in many reaches and areas where limited or no data currently exist. This report covers a portion of the available study area data. The objectives of this study include: 1) identify locations in areas of fishery management value that were likely to retain temperature loggers on a full year basis; 2) examine how water temperature varies at established locations over time both within year and among years; 3) compare data among locations within and between years and to other available data sets; and 4) relate this information to management topics such as fish passage operations, fish migration, and thresholds for life history events such as spawning.

Methods

Temperature loggers (Onset Pendant® Temperature Loggers, -4° to 158°F operating range, accuracy ± 0.95°F, (referred to as logger) were zip tied within a PVC tube (2 inch diameter by 5 inch length, schedule 80) which had at least twelve 3/8 inch bored holes perforating it on all sides. This PVC tube was placed in the inside chamber of a full size cement block. The PVC tube was run through with a section of cut standard garden hose that serves as a chaff guard (length approximately 18 inches). The garden hose section was run through by plastic coated wire (380 lb. test), which was then re-attached to the wire using two double bolted cable tie clamps (Figure 1). A length of wire was determined based upon the deployment site which was based on the intended anchoring structure (e.g., railing). The structure or bank location anchor structure was wrapped by the wire and two cable ties were used to fasten and secure the wire. The cement block was then placed into the water. Block placement varied in depth and proximity to shore with the intention of ensuring the block (with logger) would be in an area of water movement and at a depth ≥ 6 ft. at the time of deployment > 6ft deep in river sites and in the case of a fishway on structure bottoms (e.g., shallower depths of <5 ft.), dependent on water flows and fishway operations.

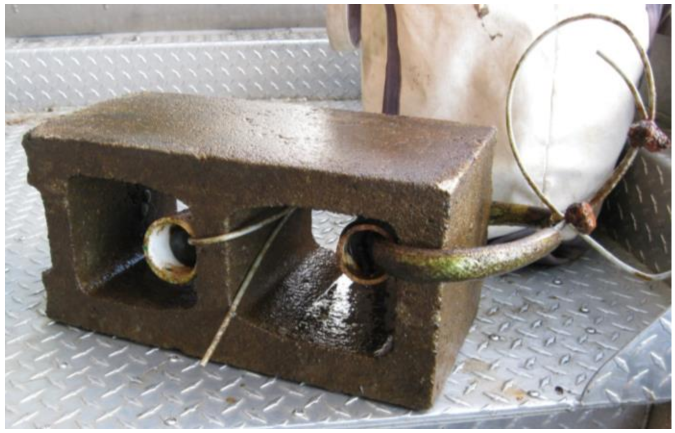

Figure 1. A standard temperature logger set-up as decribed in the methods section. The second PVC pipe section shown cable tied directly to the center of the block was a second temperature logger, from the Connecticut River Watershed Council.

River stage was considered at all deployment sites (e.g., dam operation, pond/impoundment elevation, river discharge, pump storage facility operation, and/or tidal stage; refer to Figure 2), and included the input of hydropower station operators who accompanied the Connecticut River Coordinator (Coordinator) at the time of logger deployment. Station staff at Cabot Power Station, Vernon Dam, Bellows Falls, and Wilder Dam were questioned on logger location relative to observations of tailwater elevation, river discharge and plant operation as they accompanied the Coordinator at all deployments. A Global Positioning System (Garmin 76CSx) was used to document logger deployment position (Appendix 1).

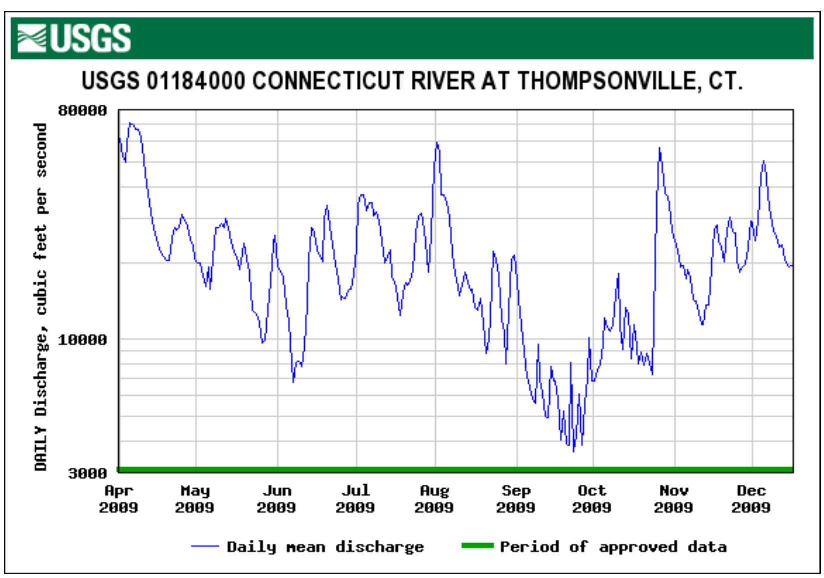

Figure 2. Measured daily discharge for the Connecticut River for period of mid-April through

mid-December 2009 at the Thompsonville, CT, USGS gauge station. Water elevations may vary on the main stem river due to peaking operations at facilities upstream of Holyoke Dam.

The study was intended to be exploratory and to determine if water temperature data could be successfully recorded on a full year basis to address existing spatial and temporal gaps in water temperature data, which have been insufficient to address fish management concerns by state and federal fisheries biologists. Hydropower dam facilities have important roles in fish passage relative to existing diadromous fish management plans and identified objectives to achieve fish restoration population abundance targets in historic habitat. Hydropower operators are responsible for complying with State and Federal agency fish passage prescriptions and operations, primarily through the Federal Energy Regulatory Commission and the Clean Water Act as well as other state laws. An area of related concern on this topic is the Vermont Yankee (VY) thermal discharge point relative to its proximity to the Vernon Dam and its upstream and downstream fishway structures (Figure 3), located 0.45 miles upstream of Vernon Dam on the same shoreline. Logger locations were identified throughout the basin in 2009 taking into account existing presence of hydropower dams, a pump storage facility, several major tributaries, and the VY thermal discharge.

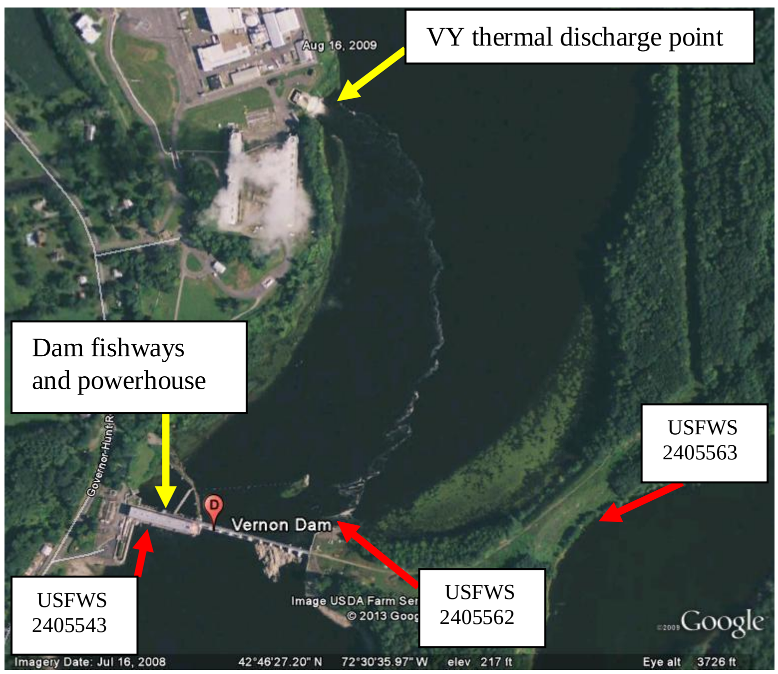

Figure 3. Aerial view of Vermont Yankee thermal discharge and the Vernon Dam and fishways rm 142, Vernon, Vermont (image from Google Earth).

After determining the ability of loggers to persist over the course of a full year and from year to year, additional steps were taken to better verify temperature data at two logger locations; logger 2405543 (fixed in tailrace of Vernon Dam's power station – Figure 4) and logger 2405561 (fixed off Vermont river bank 2.2 miles upstream of VY). Onset Model ProV2 loggers, which were quality control checked by the Connecticut River Watershed Council (CRWC) in their laboratory using a National Institute of Standards certified thermometer, were deployed in the same method as (USFWS) loggers with CRWC personnel, starting on June 12, 2012 at these two locations.

Figure 4. The location of logger 2405543 (Vernon Dam's power station tailrace), shown by yellow arrow, in proximity to fish ladder entrance, which is not operating at time of this picture. Fish ladder operates from April 15 through July 15 annually and discharges 260 cubic feet per second (CFS). Downstream fish pipe (one of two), operates from April 1 through December 31 annually and adjacent to logger, discharges at 40 CFS, from the forebay.

In addition, temperature data provided by VY temperature monitoring stations were obtained and used to compare and contrast with USFWS data at proximal locations for years of available data. The VY Vernon Dam fish ladder temperature monitoring data for the spring seasons of 2010 and 2011 were compared with the USFWS Vernon Dam tailwater logger 2405543 data. Vermont Yankee Station #7 (3.5 miles upstream of VY) data for 2009-2010 (more recent data not available) was compared with the USFWS logger 2405561 data (2.2 miles upstream of VY). Vermont Yankee's Station #7 data were also compared with the VY's Vernon Dam fish ladder data for the spring of 2010. Lastly, VY Station #3 (0.6 mile downstream of Vernon Dam) data were compared with both USFWS logger 2405543 and 2405563 (1.2 miles downstream of Vernon Dam) data. Comparisons of temperature data, mean hourly value for USFWS, and hourly VY data were conducted using Pearson's Correlation Procedure to quantify the strength of the association between the two data sets and test for significance.

Beginning in November 2012, temperature loggers were quality control and quality assurance checked using a Yellow Springs Inc. Model 85 (YSI) water quality meter for all logger station data results contained in this report. Paired readings, in a laboratory setting with a National Institute of Standards currently certified thermometer were taken for both ambient and ice bath conditions using the YSI meter. This meter was then used to examine logger accuracy in the field. Water temperatures were taken at the logger location with the YSI meter. Field temperature loggers were retrieved, downloaded and then reset to record at 1 minute intervals. The logger was placed in a 5 gallon bucket of river water, and tied to a weight so it would float suspended at intermediate depth in the bucket of water. The YSI probe was placed, suspended, adjacent to the logger in this bucket. Temperature readings were then recorded every minute, following a stabilization period (typically 5 minutes), for a 15 minute period, providing a series of 15 temperature readings that could be compared with those of the logger.

Vermont Yankee temperature data for Station #7 for the period 1974-2011 were obtained and examined for significance differences and trends in reported water temperatures using monthly daily mean values over this long-term period using linear regression and ANOVA statistical procedures. Level of significance was set at $P < 0.05$. This examination of VY data was to test whether river water temperatures had changed significantly and with or without trend over the 35 years of available record, upstream of the influence of the VY discharge.

Results

This report focuses on main stem temperature loggers deployed from Wilder Dam (Wilder, VT/Lebanon, NH) tailwater at rm 217, downstream to the Cabot Power Station (Montague, MA) tailwater at rm 120 (Figure 4A). Appendix 1 provides deployment summary information for the 16 loggers in the identified reach of the main stem Connecticut River spanning a distance of 98 river miles.

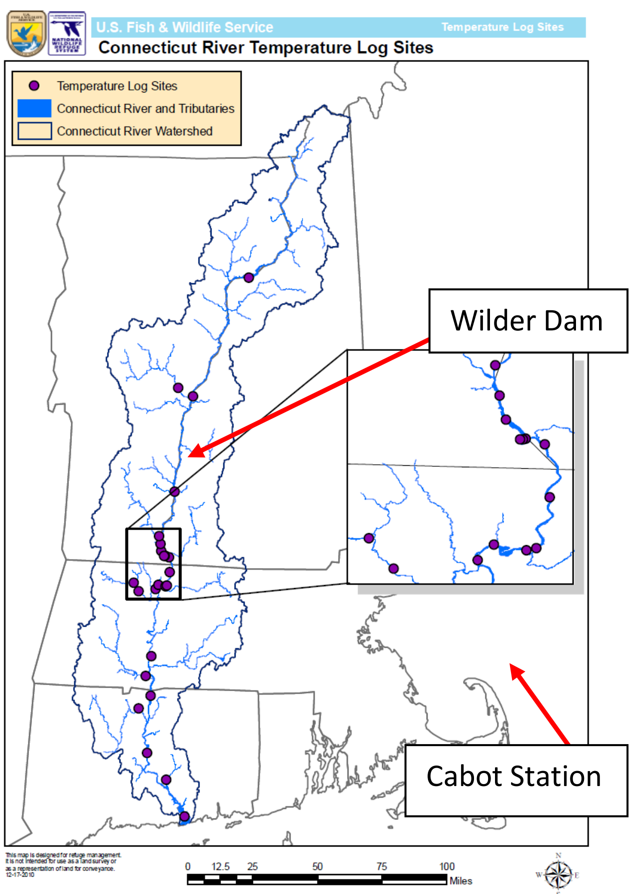

Figure 4A. The Connecticut River basin and locations of water temperature loggers deployed Fall of 2009.

Wilder Dam (2405542)

The Wilder Dam tailwater logger (2405542) at river mile 217, first deployed on September 28, 2009, was checked on November 5, 2010, when it was downloaded and re-deployed. It was next checked on October 24, 2011, at which time it could not be freed from a hang up at depth that appeared to be a submerged log. The unit was left in place and was checked again on October 1, 2012, at which time it was recovered, downloaded and redeployed. A back-up unit had been deployed on October 24, 2011, but that unit was lost at the following check. Figure 5 illustrates the temperature regimes at this site from the Fall of 2009 through the Fall of 2012. This logger was visited again on November 29, 2012, when it was checked for accuracy as described in the methods section.

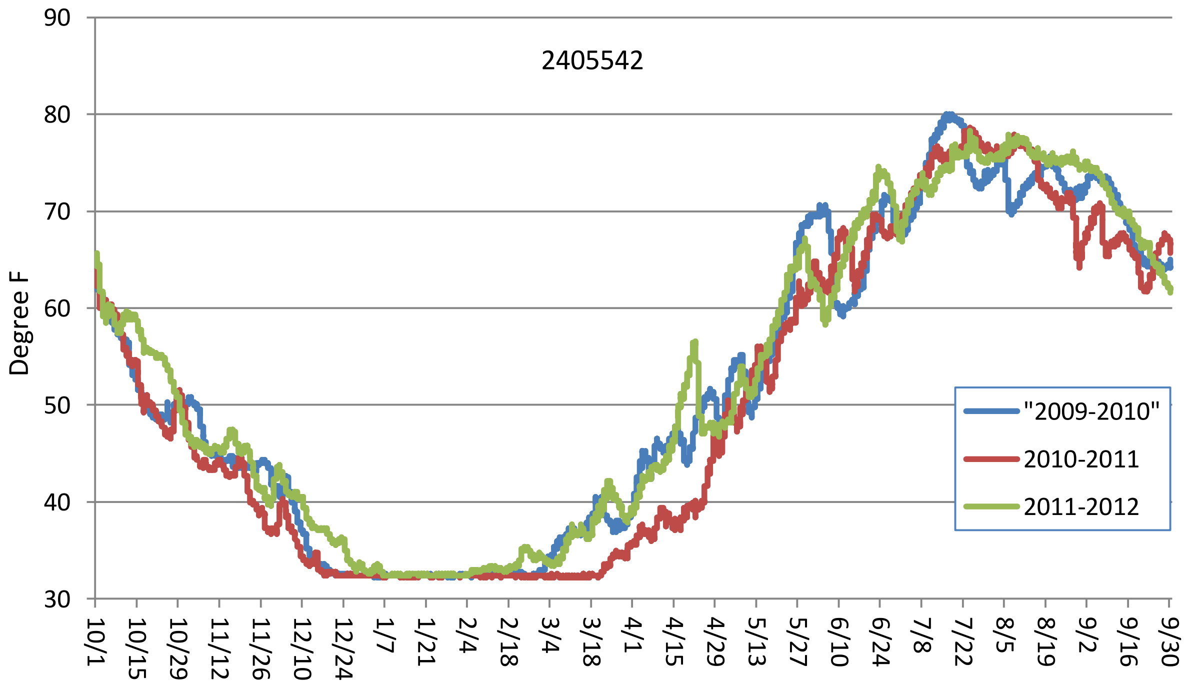

Figure 5. Wilder Dam logger (2405542) water temperature profiles for Fall 2009 through Fall of 2012.

Bellows Falls (2405544 and 2405583)

The Bellows Falls logger (2405544), at river mile 173, first deployed on September 29, 2009, was checked again on November 5, 2010, when it was downloaded and redeployed. It was next checked on October 18, 2011, when it was downloaded. It was replaced with logger (2405583) and re-deployed on the same structure to protect the exposed anchor wire from ice damage from the suspended sluice way. The logger was left in place and was checked again on October 1, 2012, at which time it was recovered, downloaded and re-deployed. The logger was checked again on November 19, 2012, downloaded, checked for accuracy, and re-deployed. Figure 6 illustrates the water temperature profile for this site from the Fall of 2009 through Fall 2012.

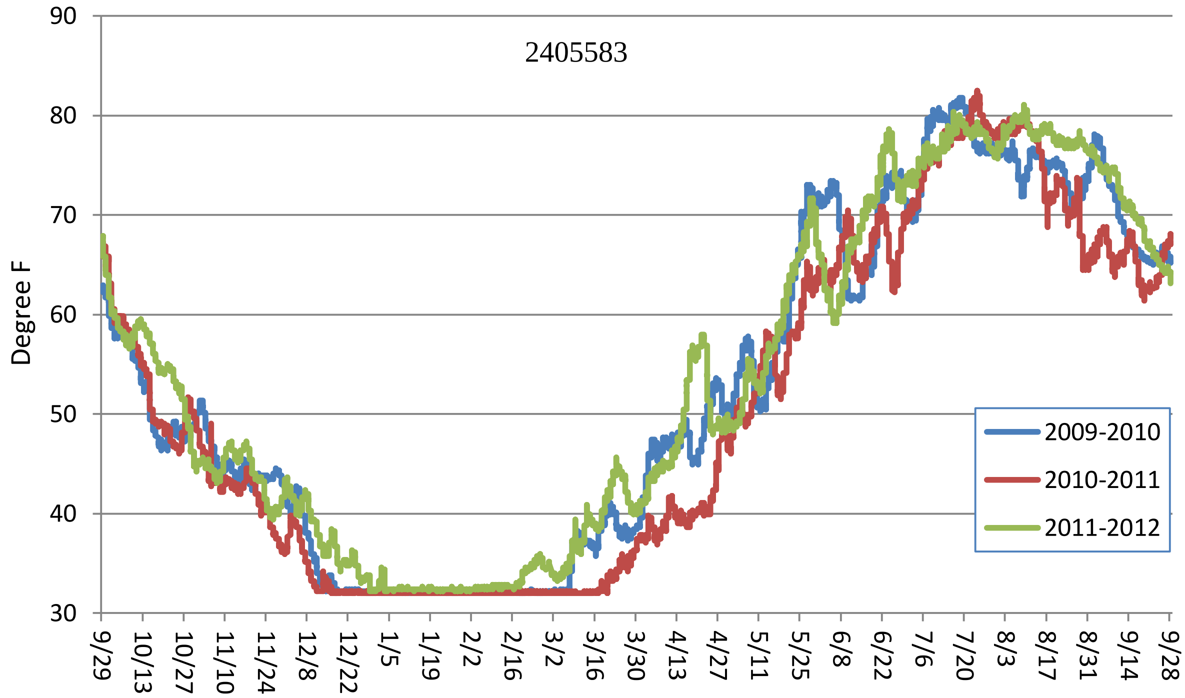

Figure 6. Bellows Falls Station logger (2405583) water temperature profiles for Fall 2009 through Fall of 2012.

Vernon Dam Pool – Brattleboro, VT - Route 9 Bridge (2405559)

The Vernon Pool, Route 9 Bridge logger (2405559), at river mile 151, was first deployed on October 14, 2009, and was checked again on October 14, 2010, when it was downloaded and re-deployed. It was next checked on October 18, 2011, when it was downloaded and then re-deployed. The unit was checked again on November 9, 2012, at which time it was recovered, downloaded and re-deployed. Figure 7 illustrates the water temperature profiles at this site from the Fall of 2009 through Fall 2012.

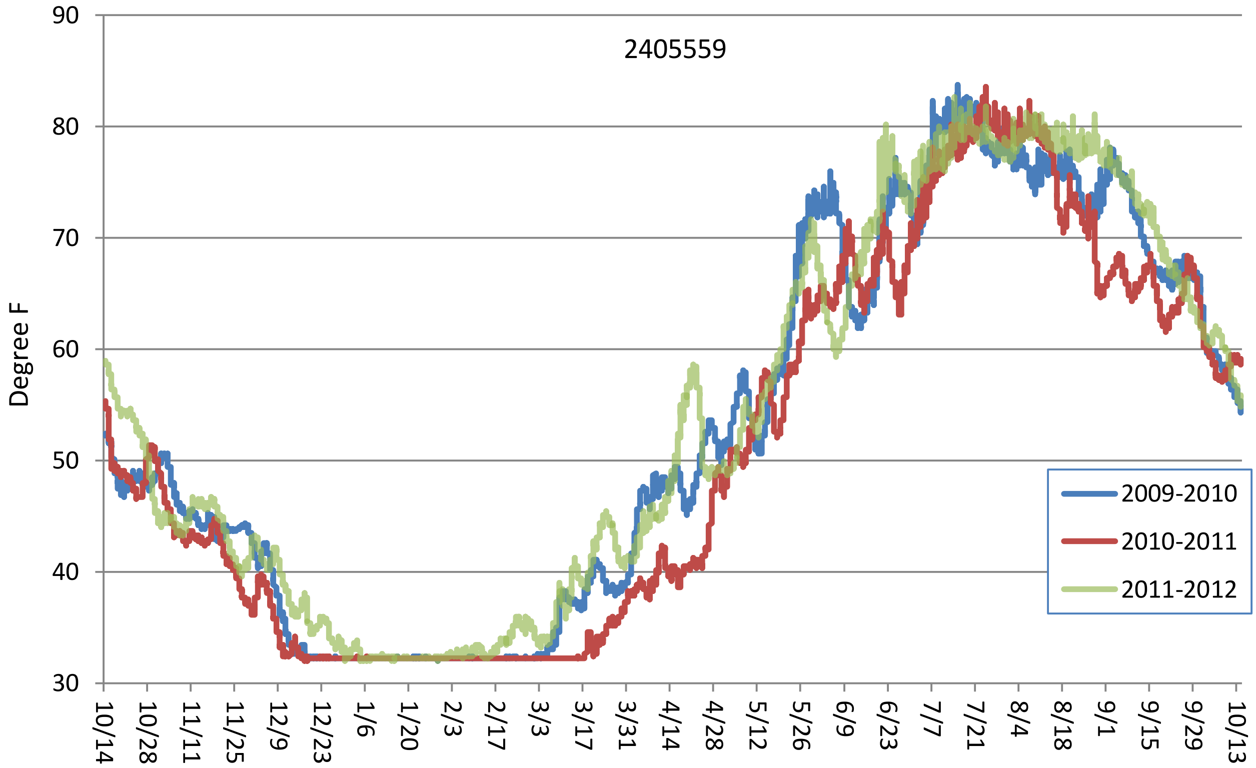

Figure 7. Vernon Dam Pool, Route 9 bridge crossing, Brattleboro, VT logger (2405559) water temperature profiles for Fall 2009 through Fall 2012.

Vernon Dam Pool – Hinsdale, NH – railroad bridge (2405560)

The Vernon Pool, Hinsdale railroad bridge logger (2405560), at river mile 147, was first deployed on October 14, 2009, and was checked again on October 14, 2010, when it was downloaded and redeployed. It was next checked on October 18, 2011, when it was downloaded and redeployed. The logger was checked again on October 11, 2012, when it was observed on the shoreline at the waterline. Figure 8 for this site shows a clearly pronounced shift in daily recorded temperature values that is expected to relate to the time when the logger was displaced from the river to the bank on or around June 20, 2012.

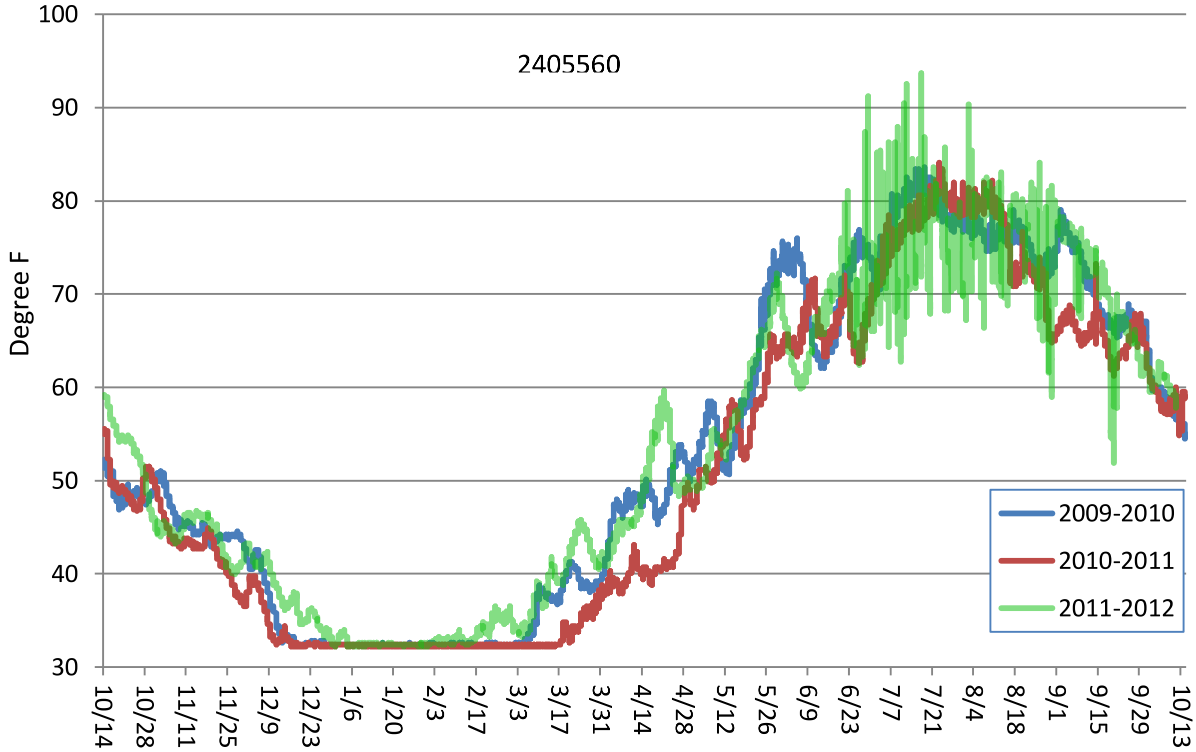

Figure 8. Vernon Dam Pool, railroad bridge crossing, Hinsdale, NH, logger (2405560) water temperature profiles from Fall 2009 through Fall 2012.

Vernon Dam Pool – 2.2 miles upriver of VY, Vernon, VT (2405561)

The Vernon Pool, Vernon VT logger (2405560), at river mile 144, was first deployed on October 14, 2009, and was checked again on October 14, 2010, when it was downloaded and redeployed. It was next checked on October 18, 2011, when it was downloaded and redeployed. The logger was checked again on June 12, 2012, not downloaded, when a second temperature logger from the Connecticut River Watershed Council (CRWC), was fixed to the same cement block and was redeployed. The logger was checked on October 11, 2012, when it was downloaded and redeployed along with the CRWC logger. Figure 9 illustrates water temperature profile changes for this site over the course of a year beginning in the Fall 2009. Temperature data from the CRWC logger, at the same time interval/frequency (20 minute time intervals, on the hour) were paired with USFWS logger data. Over the period of paired readings, a total of 8,712 observations were compared (Figure 10). The USFWS logger recorded a total of 68 observations lower than the CRWC logger and 8,644 observations that were greater. The mean difference between all observed temperature differences was 0.16°F with a standard deviation of 0.20°F. There are three data reads by CRWC that appear to be outliers of unknown origin on July 8, 2012. Overall, the difference in temperatures between the two loggers was less than or equal to plus or minus 0.5°F for 8,668 observations or 99.5% of observations.

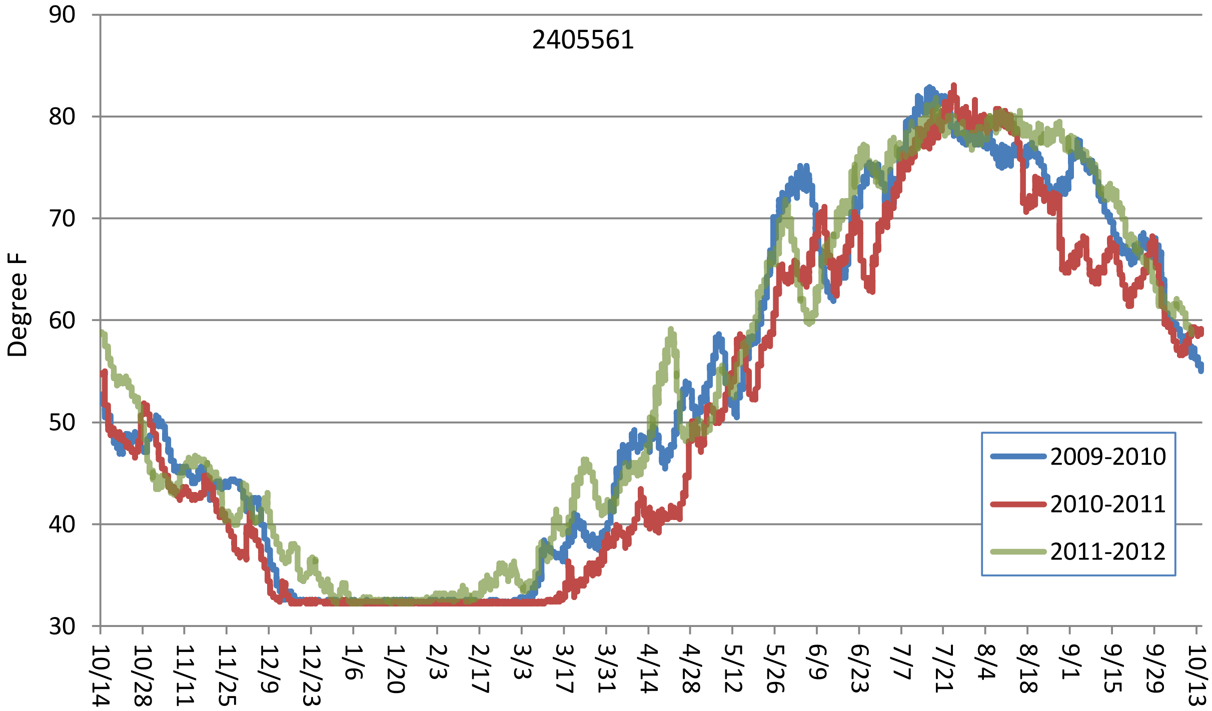

Figure 9. Vernon Dam Pool logger (2405561), 2.2 rm upstream of VY, Vernon, VT, water temperature profiles from Fall 2009 through Fall 2012.

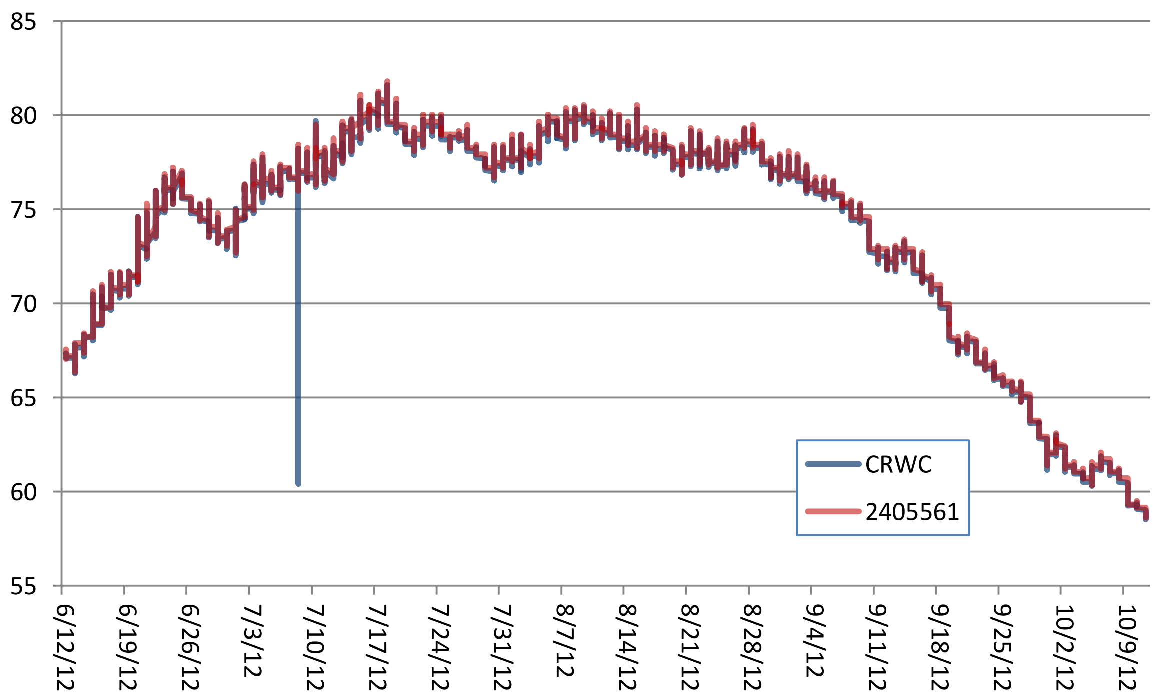

Figure 10. Time series of paired logger readings for the USFWS logger (2405561) and the CRWC logger (Spring-Fall 2012) located 2.2 miles upstream of VY.

In addition, hourly water temperature data for VY Station #7 (upstream approximately 3.5 miles from the plant) was compared with the USFWS 2405561 data (upstream 2.2 miles from discharge) for the only period of record available at this time (Fall 2009 through Fall 2010). Figure 11 illustrates the plotted hourly water temperature values for the two loggers, at their respective locations. Outlier data from VY, or equipment issues, are shown for November 11, 2009, possibly May 11, 2010, and July 23, 2010. Data between the two sites, aside from the VY outlier data, track closely, with a slight but consistently higher value reported by the USFWS logger, which as noted, is located further downstream than VY Station #7. The Pearson correlation coefficient for these data (10/21/09 – 10/4/10) is $r = 0.99946$, $P < 0.0001$, $n = 8,349$ pairs.

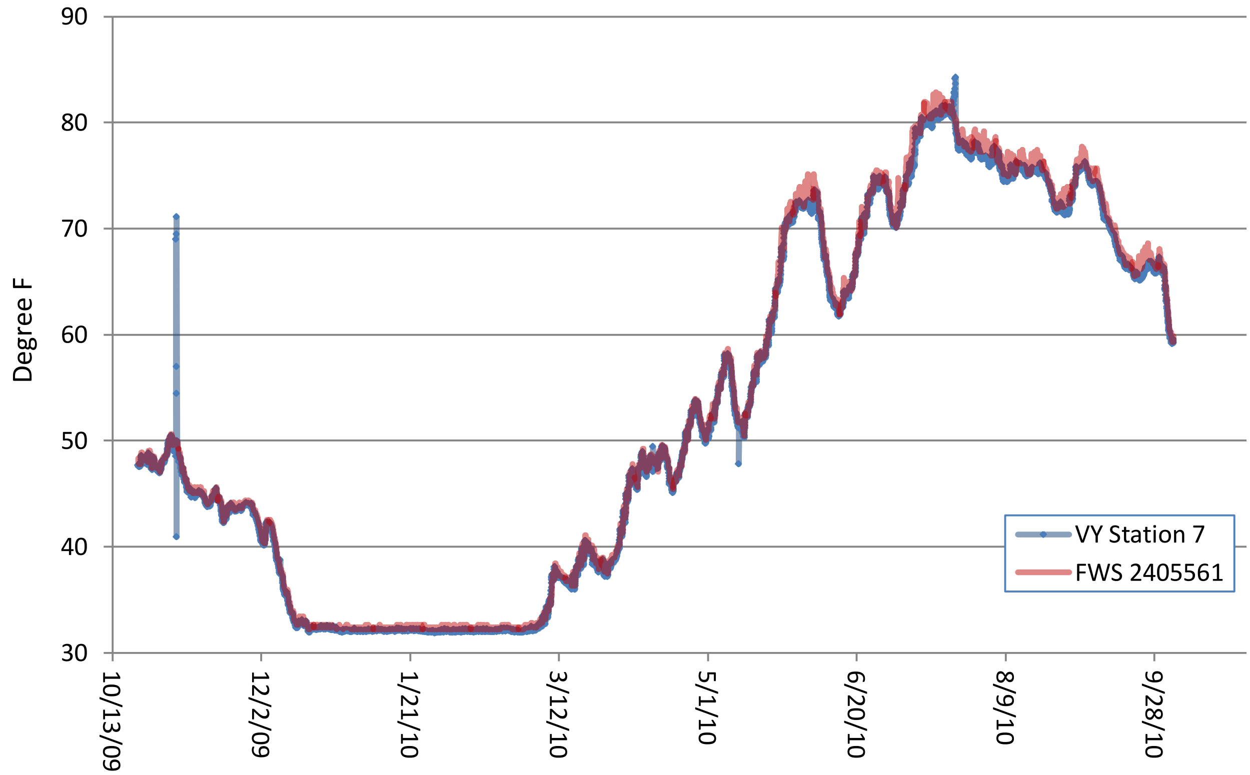

Figure 11. Vermont Yankee Station #7 water temperature data (hourly), plotted with USFWS logger (2405561) hourly data reads for the Fall 2009 through the Fall 2010.

Vernon Dam Pool – Vernon Dam, Hinsdale, NH (2405562)

The Vernon Dam Pool logger (2405562), at river mile 142.1, is located along a rock bank on near the eastern edge of the Vernon Dam upstream abutment (Figure 3), in the impoundment and is the first logger downstream of the VY discharge point on the opposite shore. The logger was first deployed on October 14, 2009, and was checked again on October 14, 2010, when it was downloaded and redeployed. It was next checked on October 18, 2011, when it was downloaded and re-deployed. The logger was checked again on November 9, 2012, when it was downloaded, checked for accuracy, and re-deployed. Figure 12 illustrates water temperature profiles for this site over the course of a full year beginning in the Fall of 2009 through Fall 2012. Vermont

Yankee was offline from April 27, 2010, through May 21-22, 2010, based on records provided by VY.

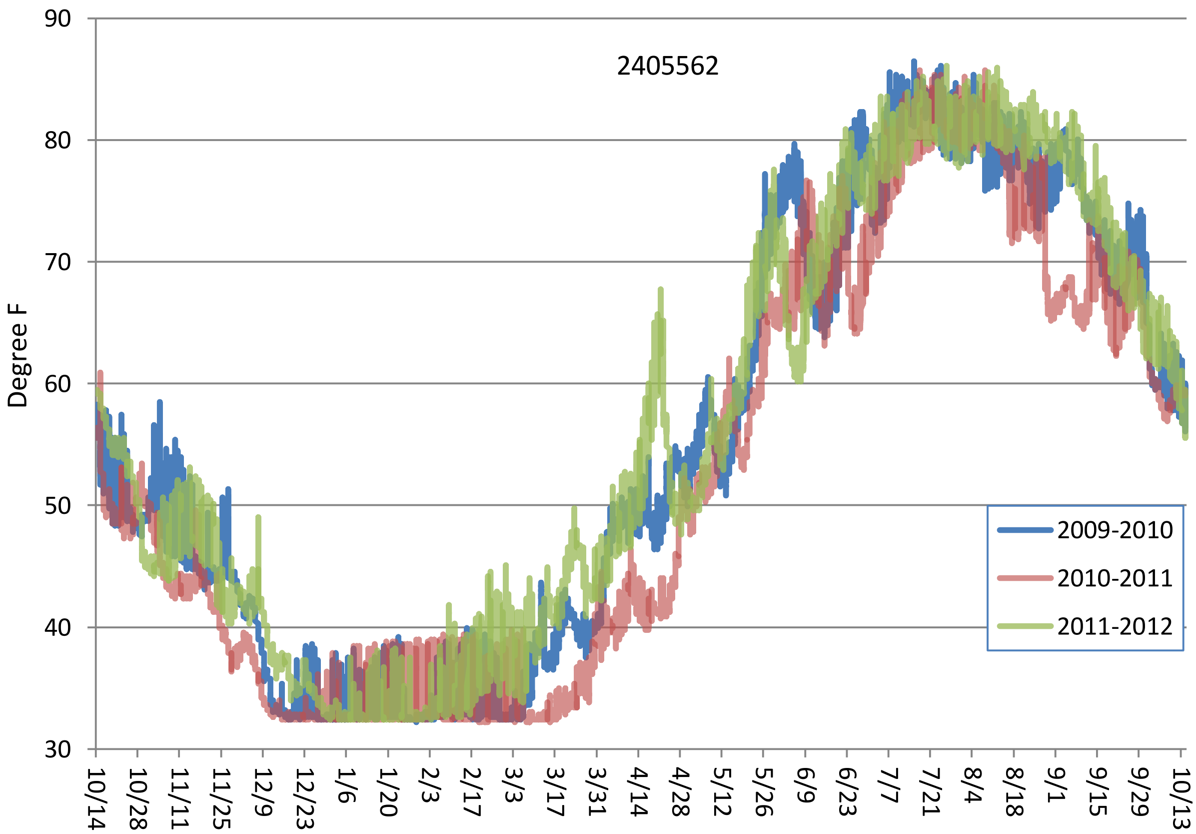

Figure 12. Vernon Dam impoundment dam face logger (2405562) water temperature profiles for Fall 2009 through the Fall 2012; first logger located downstream of VY discharge. VY was off line April 27, 2010 through May 21-22, 2010.

Vernon Dam Tailwater, Vernon, VT (2405543)

The Vernon Dam tailwater logger (2405543), at river mile 142, was first deployed on September 28, 2009, and was checked again on October 4, 2010, when it was downloaded and re-deployed (Figure 3 and 4). It was next checked on October 24, 2011, when it was downloaded and re-deployed. The logger was checked again on June 12, 2012, but not downloaded, when a second temperature logger from the CRWC was fixed to the same cement block and was redeployed. The loggers were checked next on October 11, 2012, and were downloaded and re-deployed. Figure 13A illustrates the water temperature profile changes for a full year beginning in the Fall 2009. Temperature data from the CRWC logger, at the same time interval/frequency (20 minute interval, on the hour), where paired with USFWS logger data. Over the period of paired readings, a total of 8,704 observations were compared (Figure 14). The USFWS logger recorded a total of 9 observations lower than the CRWC logger and 8,695 were higher. The mean difference between all observed temperature differences was 0.34° F with a standard deviation (SD) of 0.06. Overall, the difference in temperatures between the two loggers was less than or equal to plus or minus 0.5°F for 8,655 observations or 99.4% of observations. On November 19, 2012, the logger was checked for accuracy.

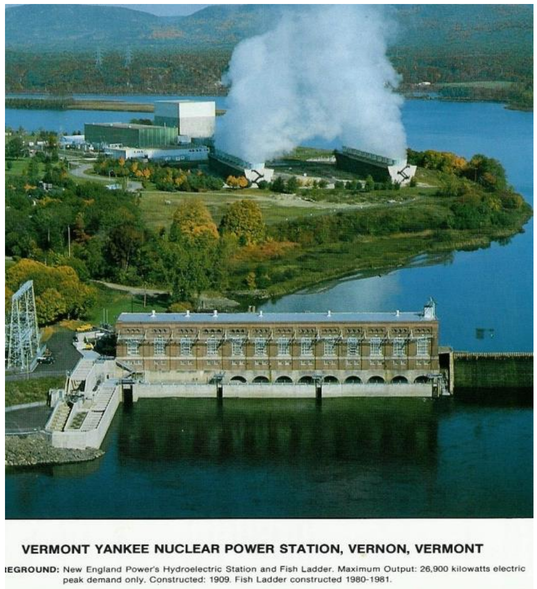

Figure 13. An aerial image of the Vernon Dam power station and its tailwater. The upstream fish ladder is located on left side (Vermont shoreline), downstream fish bypasses discharge through the power station. Vermont Yankee cooling towers in operation, background.

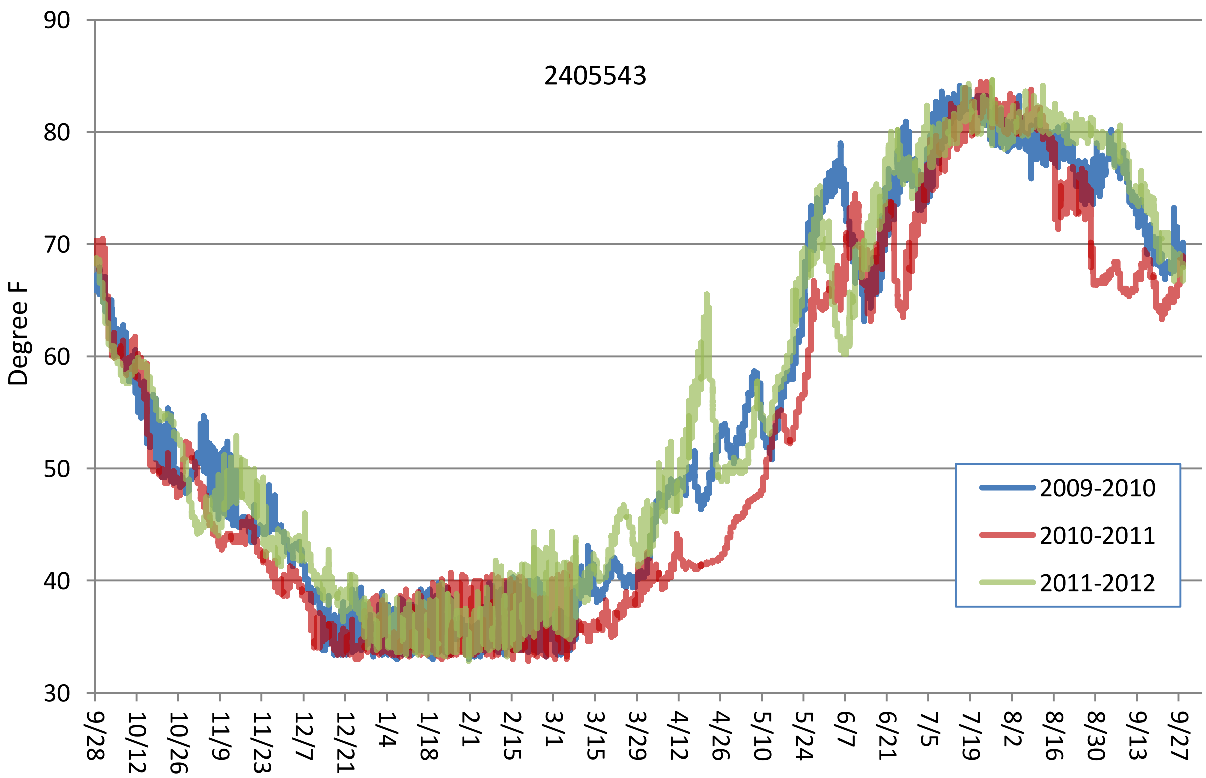

Figure 13A. Vernon Dam tailwater, Vernon, VT, logger (2405543) water temperature profiles from Fall 2009 through Fall 2012. VY was off line April 27, 2010, through May 21-22, 2010.

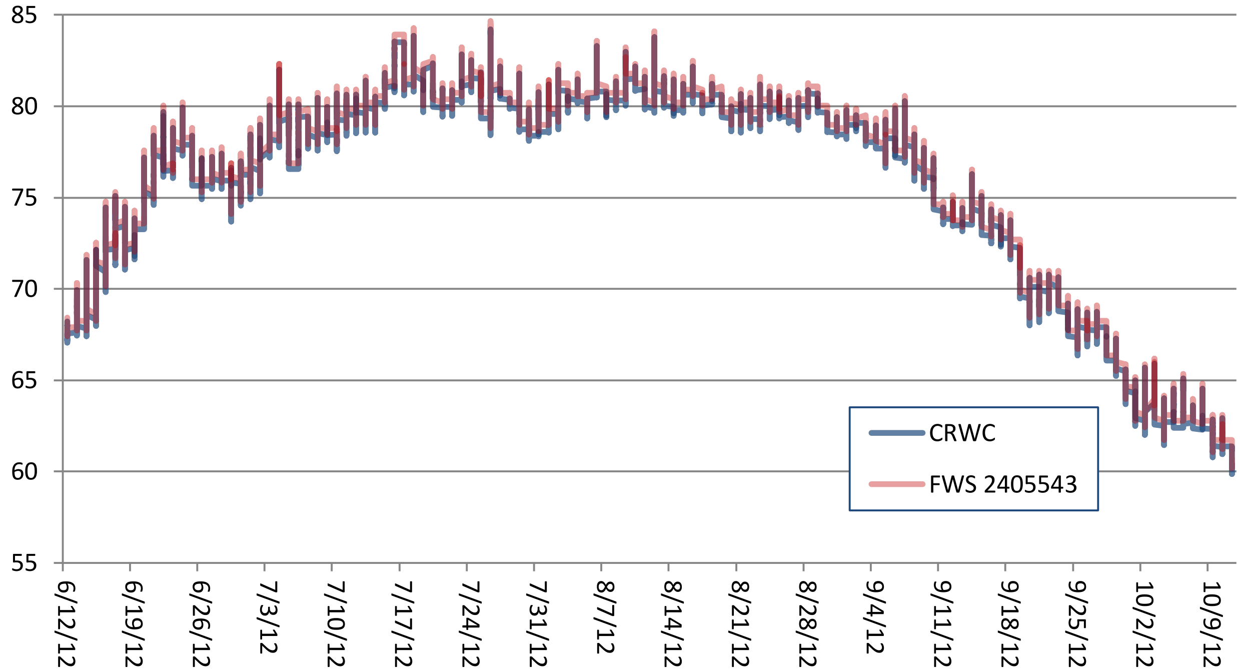

Figure 14. Time series of paired logger temperature readings from USFWS logger (2405543) and the CRWC logger (Spring-Fall 2012), Vernon Dam tailwater.

Vermont Yankee data for their Vernon Dam fish ladder logger were compared with the USFWS 2405543 logger data for the periods of available data which included two spring seasons, 2010 and 2011. Figure 15 illustrates the paired data for the period May 7 through July 7, 2010, and shows a high degree of consistency between the two loggers, noting that the VY logger was in the fish ladder and the USFWS logger was in the tailrace in close proximity to the entrance of this fish ladder. The Pearson correlation coefficient for this data comparison is $r = 0.99783$, $P < 0.0001$, $n = 1{,}462$.

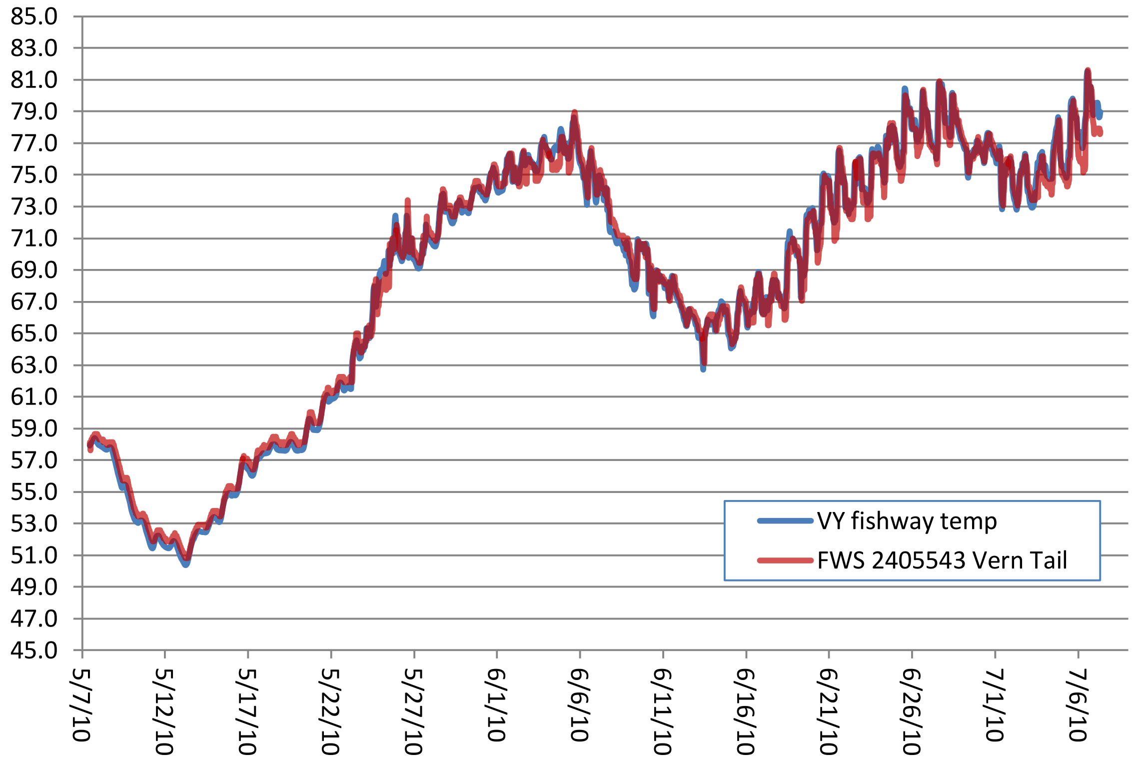

Figure 15. Comparison plot of water temperatures recorded by VY's fish ladder logger and the USFWS logger 2405543 located in the tailrace, Spring 2010. VY was off line April 27 through May 21-22, 2010.

Vermont Yankee fish ladder data for May 23 through July 13, 2011, were also compared to the USFWS 2405543 logger (Figure 16). The two data sets again show a high degree of similarity with the exception of a few VY data points that appear as outliers on June 14. The Pearson correlation coefficient for this data comparison is $r = 0.99267$, $P < 0.0001$, $n = 1{,}225$.

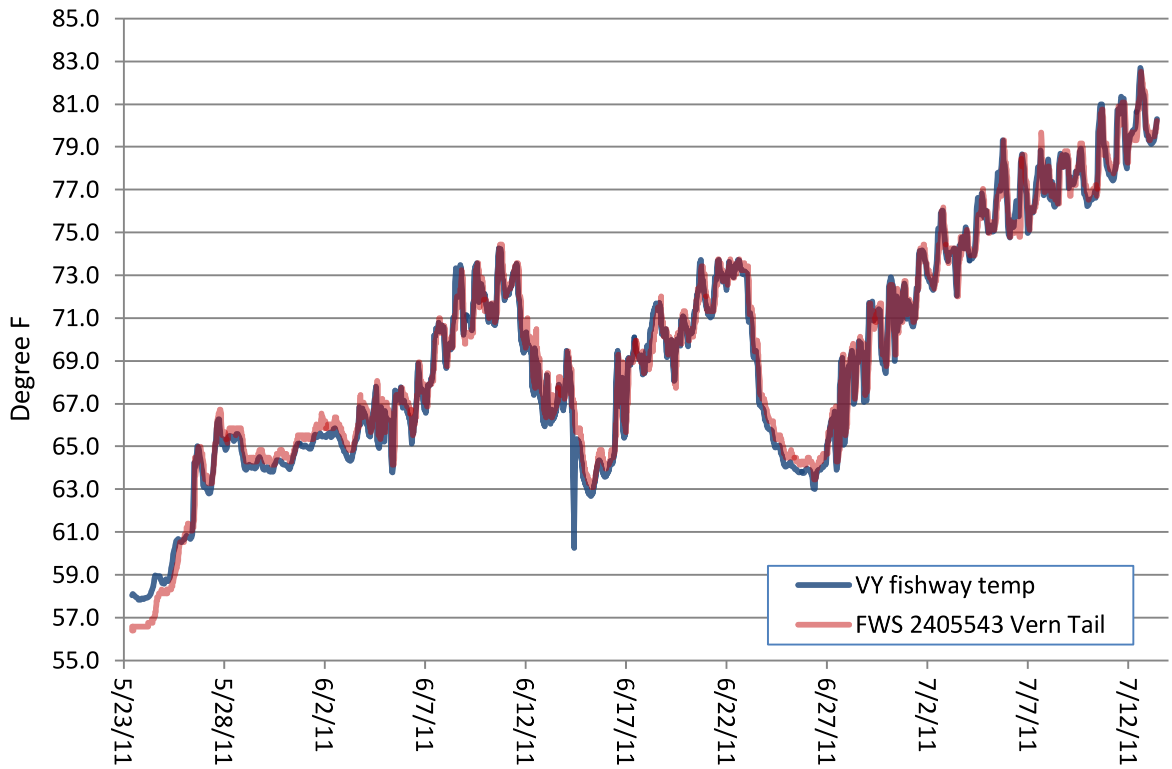

Figure 16. Comparison plot of water temperatures recorded by VY's fishway logger and the USFWS logger 2405543 located in the tailrace, Spring 2011.

In addition, hourly water temperature data, for VY Station #3 (downstream of Vernon Dam, 0.6 mile) was compared with 2405543 logger data for the only period of record available at this time (9/28/09 through 12/31/10). Figure 17 illustrates the plotted hourly water temperature values for the two sets of data, at their respective locations. Outlier data from VY over a six hour span are shown for November 14, 2009. The Pearson correlation coefficient for these data is $r = 0.99738$, $P < 0.0001$, $n = 11,022$. Temperature data between the two sites indicate a slightly higher read by the USFWS logger which is expected as the VY discharge is not considered fully mixed until 0.6 miles downstream at the location of VY Station #3 (Aquatec 1977). The variable rate of increases and decreases in temperatures between the two sites shows strong agreement in Figure 17.

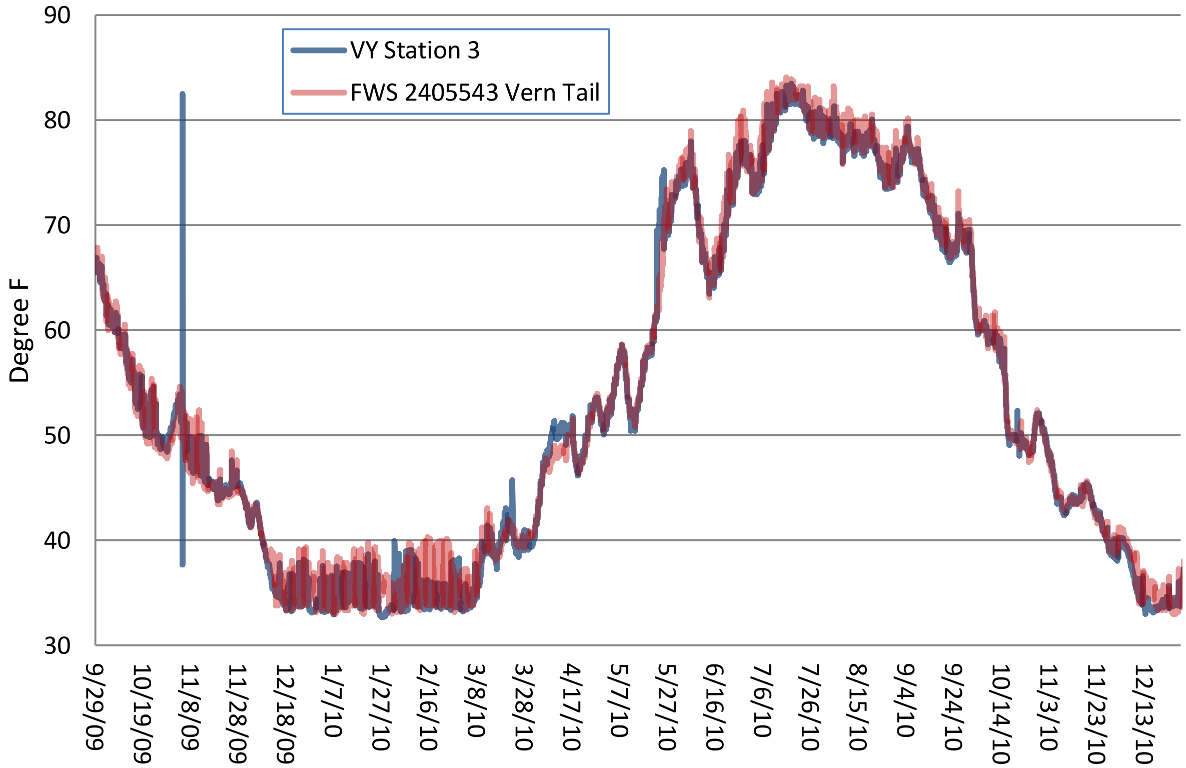

Figure 17. Vermont Yankee Station #3 water temperature data (hourly) plotted with USFWS logger 2405543 hourly data for Fall 2009 through 2010. VY was off line April 27, 2010, through May 21-22, 2010.

Turners Falls Dam Pool, 1.2 miles downstream of Vernon Dam, Hinsdale, NH (2405563)
The Turners Falls Dam Pool logger (2405563), at river mile 140.8, is located approximately 1.2 miles downstream of the Vernon Dam, and approximately 0.6 miles downstream of the VY Station #3. This logger was first deployed on October 21, 2009, and was checked again on October 8, 2010, when it was downloaded and re-deployed. It was next checked on October 11, 2011, when it was downloaded, and re-deployed. The logger was checked again on November 5, 2012, when it was checked for accuracy, downloaded and re-deployed. Figure 18 illustrates the water temperature profile changes for this site for a full year beginning in Fall 2009 through the Fall 2012. Outlier data are shown on July 29, 2012, and on August 31, 2012.

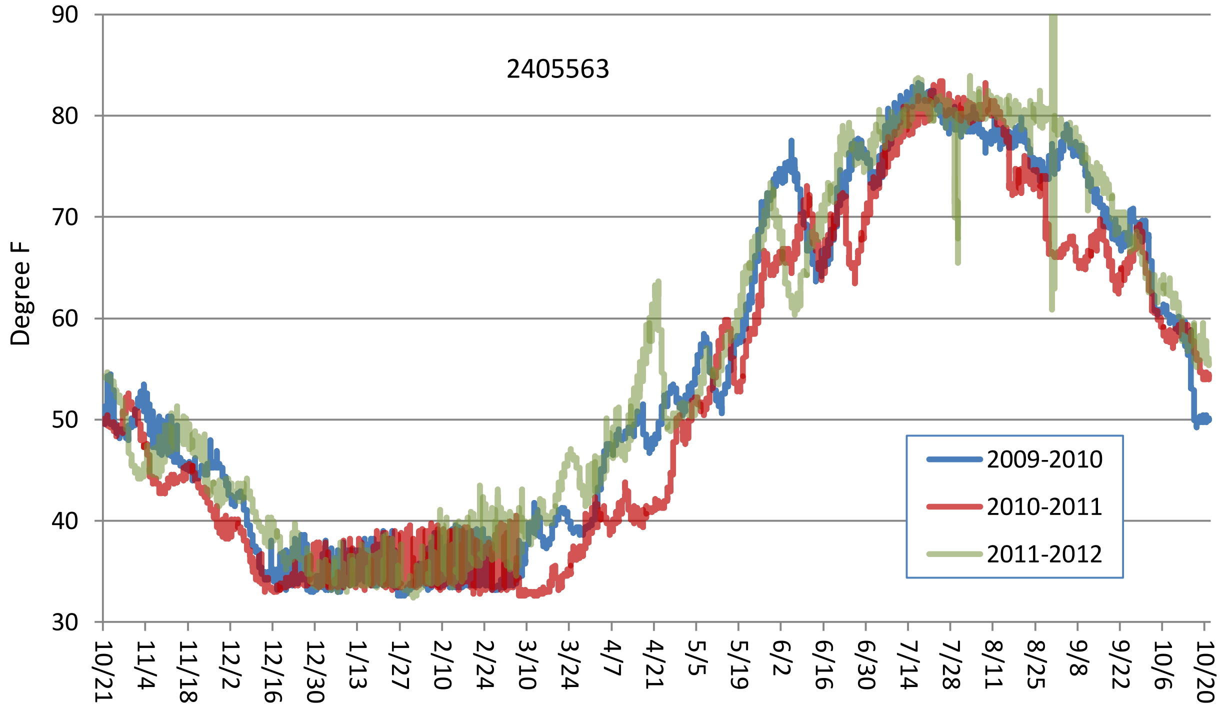

Figure 18. Turners Falls Dam Pool, logger (2405563) located 1.2 rm downstream of Vernon Dam, water temperature profiles from the Fall 2009 through Fall 2012. VY was off line April 27, 2010 through May 21-22, 2010.

In addition, hourly water temperature data, for VY Station #3 (downstream of Vernon Dam, 0.6 mile) was compared with 2405563 data for the only period of record available at this time (10/21/09 through 12/31/10). Figure 19 illustrates the plotted hourly water temperature values for the two sets of data, at their respective locations. The Pearson correlation coefficient for these data is $r = 0.99822$, $P < 0.0001$, $n = 10,470$. Outlier data from VY over a six hour span are shown for November 4, 2009. The variable rate of increases and decreases in temperatures between the two sites shows strong agreement in Figure 19.

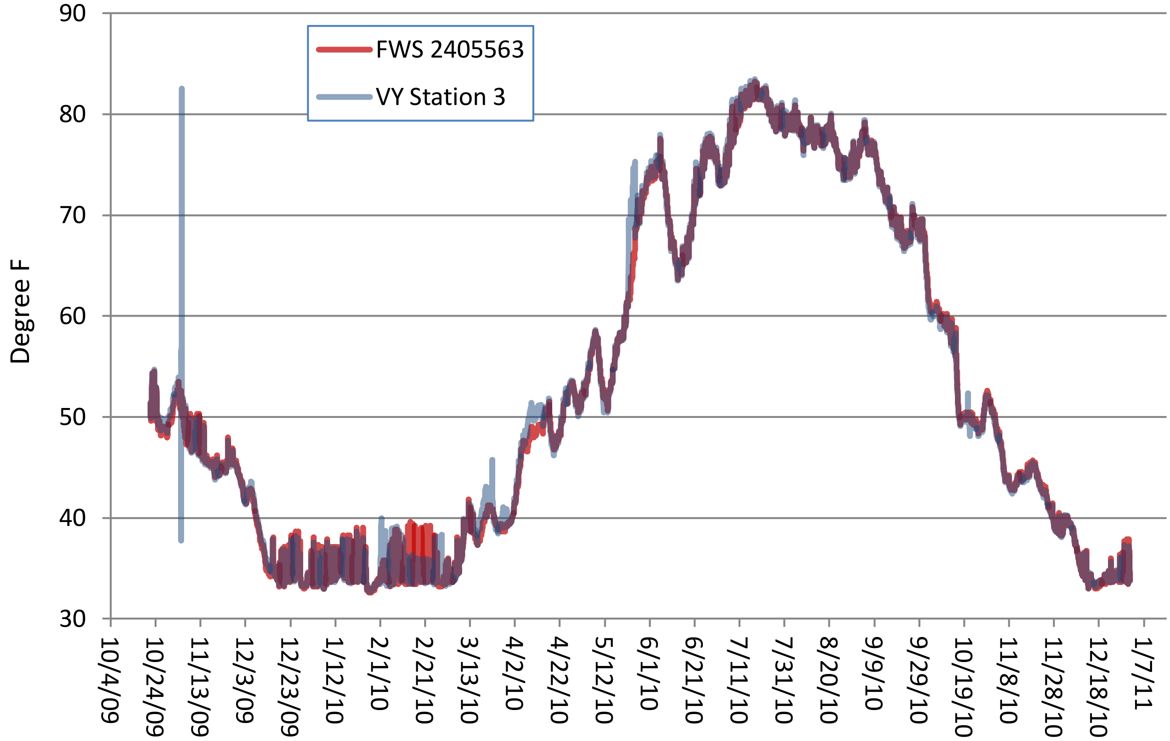

Figure 19. Vermont Yankee Station #3 water temperature data (hourly), plotted with USFWS logger 2405563 hourly data reads for Fall 2009 through December 31, 2010. VY was off line April 27, 2010 through May 21-22, 2010.

Turners Falls Dam Pool, downstream of Ashuelot River confluence, Hinsdale, NH (2405566)

The Turners Falls Dam Pool logger (2405566), at river mile 139, is located downstream of the confluence of the Ashuelot River approximately 0.8 miles in Hinsdale, NH. The logger was first deployed on October 21, 2009, and was checked again on October 8, 2010, when it was downloaded and re-deployed. It was next checked on October 11, 2011, when it was downloaded and re-deployed. The logger was checked again on November 5, 2012, when it was downloaded, checked for accuracy, and re-deployed. Figure 20 illustrates water temperature profile changes for this site for a full year beginning in the Fall 2009 through the Fall 2012.

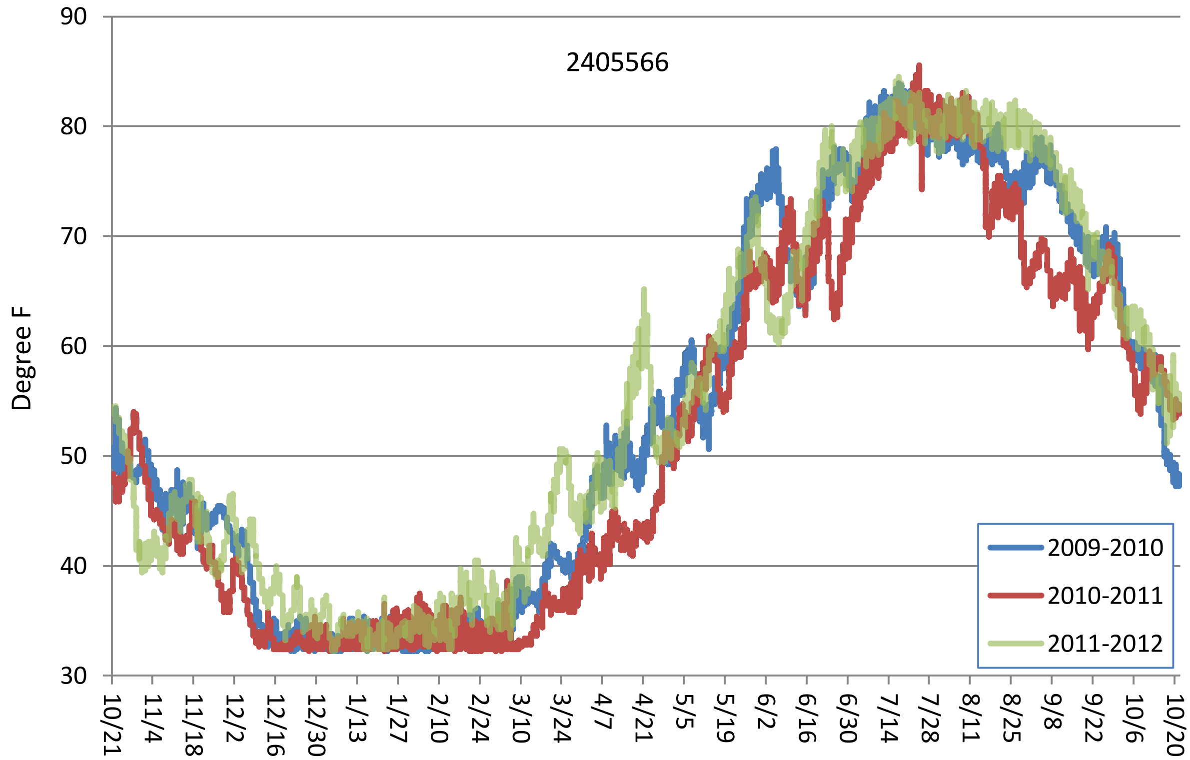

Figure 20. Turners Falls Dam Pool, downstream of Ashuelot River, USFWS logger (2405566) water temperature profiles for Fall 2009 through Fall 2012.

Turners Falls Dam Pool, Route 10 Bridge area, Northfield, MA (2405554)

The Turners Falls Dam Pool logger (240556), at river mile 133, was along a bank repair site, downstream of the Route 10 Bridge. The logger was first deployed on October 1, 2009, and was checked again on October 8, 2010, when it was downloaded and redeployed. It was next checked on October 11, 2011, at which time it was buried under sediment. Tropical Storm Irene had occurred in late Summer and this bank had been impacted with some debris that created a depositional area. As a consequence, only one full year of data are presented for this site (Figure 21), which illustrates the temperature profile for that site from the Fall 2009 through the Fall 2010.

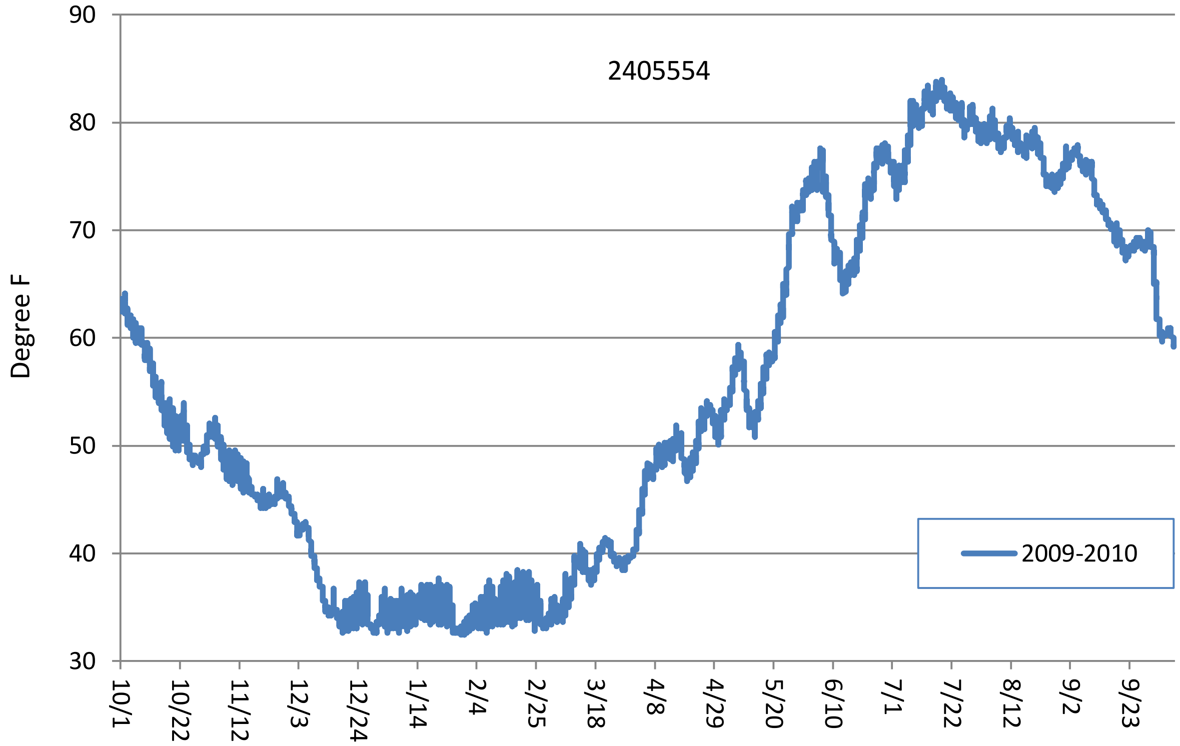

Figure 21. Turners Falls Dam Pool logger 240554 water temperature profile from the Fall 2009 through Fall 2010.

Turners Falls Dam Pool, Renassance Rock, Gill, MA (2405553)

The Turners Falls Dam Pool logger (2405553), at river mile 130, was near a rock outcrop on the Gill, MA shoreline. The logger was first deployed on October 1, 2009, and was checked again on October 8, 2010. The logger anchor cable line could not be located due to water elevation. The logger was checked again on October 11, 2011, at which time it was downloaded and re-deployed. The logger was next checked on November 5, 2012, and it was not retrieved. As a consequence, only one full year of data are presented for this site (Figure 22), which illustrates the temperature profile for that site from the Fall 2009 through Fall 2010.

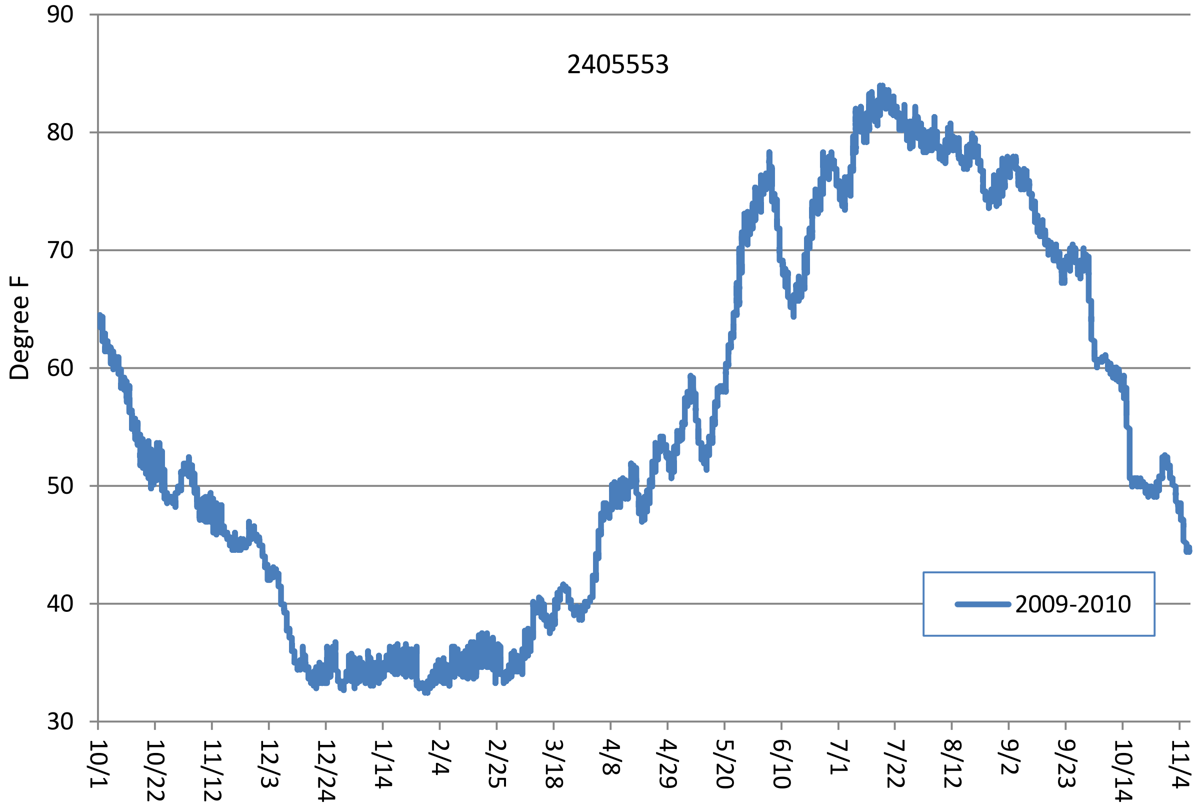

Figure 22. Turners Falls Dam Pool, Renassance Rock logger (2405553) water temperature profiles for Fall 2009 through Fall 2010.

Turners Falls Dam Pool, French King Rock site, Erving, MA (2405552)

The Turners Falls Dam Pool logger (2405552), at river mile 127, is located upstream of the French King Bridge in Erving, MA. This location is approximately 0.7 miles downstream of the Northfield Mountain Pump Storage intake cove and approximately 0.7 miles upstream of the confluence of the Millers River. The logger was first deployed on October 1, 2009, and was checked again on October 8, 2010, when it was downloaded and re-deployed. It was next checked on October 11, 2011, when it was downloaded and re-deployed. The logger was checked again on November 5, 2012, at which time it was observed moved up on the waterline of the bank (lower water elevation). The logger was downloaded, checked for accuracy, and re-deployed. Figure 23 for this site illustrates the water tempereature profiles at this site from Fall 2009 through Fall 2012. The period of logger displacement is not evident on Figure 23 as the time series was abbreviated on this figure to provide for consistent among year comparisons by date. However, the data show pronounced short period shifts in temperature values that start in late October 2012, which are not shown in this figure. Outlier data appears in the figure for July 19, 24, 25, 2011, it is unclear what the cause of these lower values (outside of expected range of variability) are.

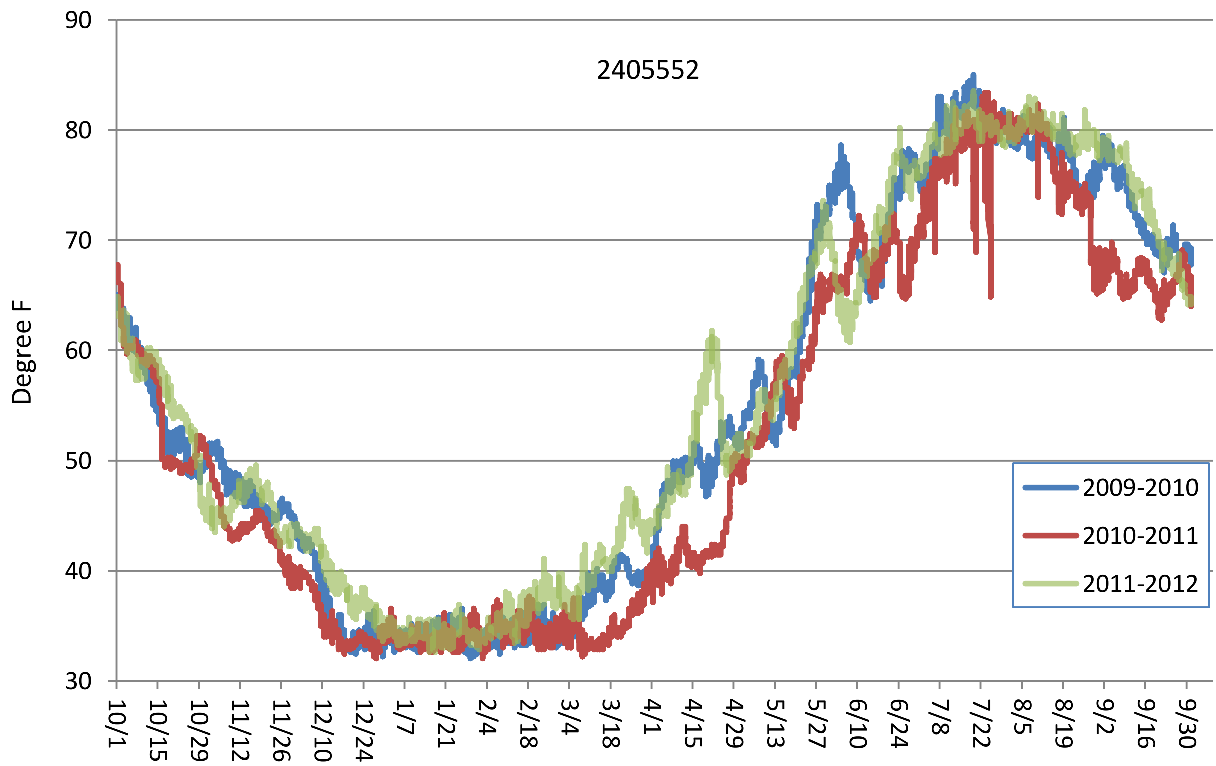

Figure 23. Turners Falls Dam Pool, French King Rock reach, logger (2405552) water temperature profiles for Fall 2009 through Fall 2012.

Turners Falls Dam Pool, Horserace Reach, Gill, MA (2405551)

The Turners Falls Dam Pool logger (2405551), at river mile 125.6,is located in the river reach referred to as the Horserace, and is approximately 0.6 miles downstream of the confluence of the Millers River. This logger was first deployed on October 1, 2009, and was checked again on October 8, 2010, when it was downloaded and re-deployed. It was checked again on October 11, 2011, when it was downloaded and re-deployed. The logger was next checked on November 5, 2012 when it was downloaded, checked for accuracy, and re-deployed. Figure 24 illustrates the temperature regimes at this site from Fall of 2009 through Fall 2012.

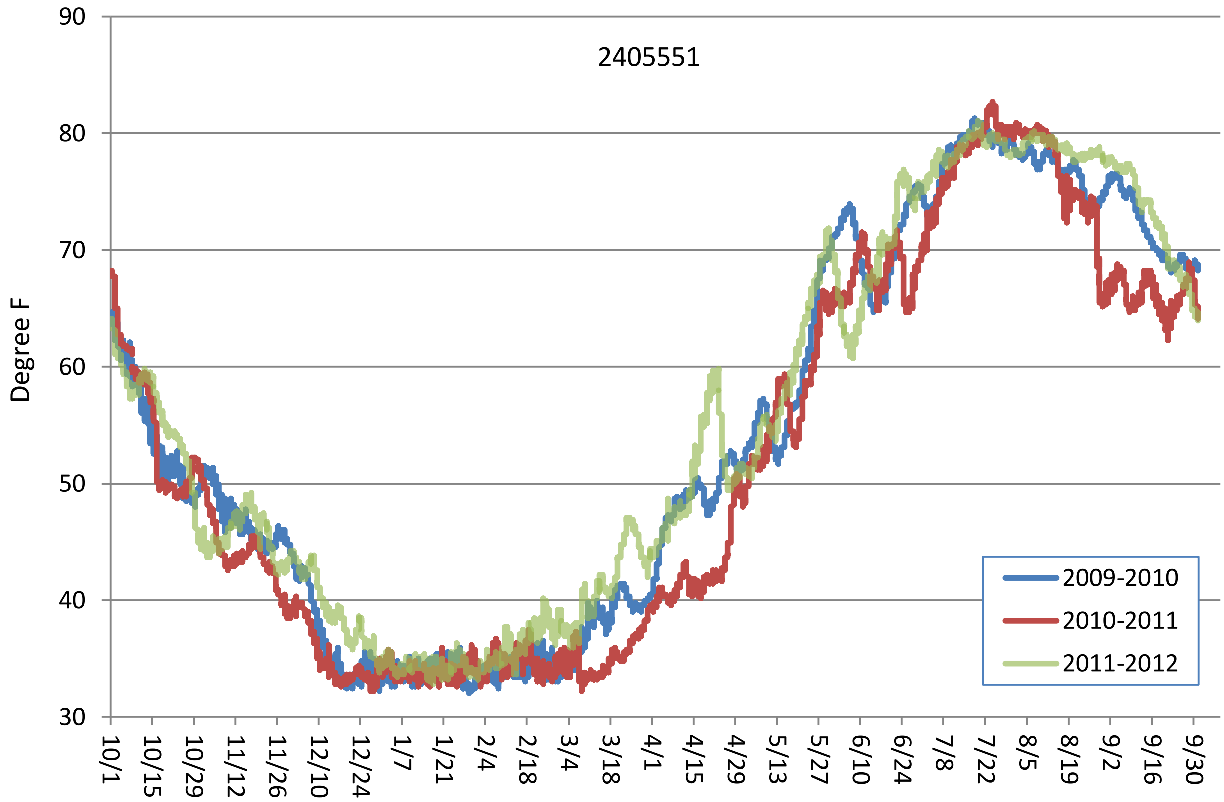

Figure 24. Turners Falls Dam Pool, Horserace reach logger (2405551) water temperature profiles for Fall 2009 through Fall 2012.

Turners Falls Dam Gatehouse, "New" Canal Fishway Entrance, Montague, MA (2405550)
The Turners Falls Dam Gatehouse "New" Canal Fishway Entrance logger (2405550), at river mile 122, is in the power canal. This location is subject to complete dewatering during canal outages in the Fall. Canal outages occurred from September 11 through September 18, 2011, and again from September 9 through September 16, 2012, when the logger would have been exposed to air. The logger was first deployed on October 1, 2009, and was checked again on October 4, 2010, when it was downloaded and re-deployed. It was next checked on October 17, 2011, when it was downloaded and re-deployed. The logger was visited on December 4, 2012, when it was checked for accuracy, downloaded, and re-deployed. Figure 25 illustrates the temperature regimes at this site from the Fall of 2009 through the Fall of 2012. As mentioned above, the two canal outages (dewatering events) are clearly visible in the plotted data for September 2011 and 2012 over a period of days.

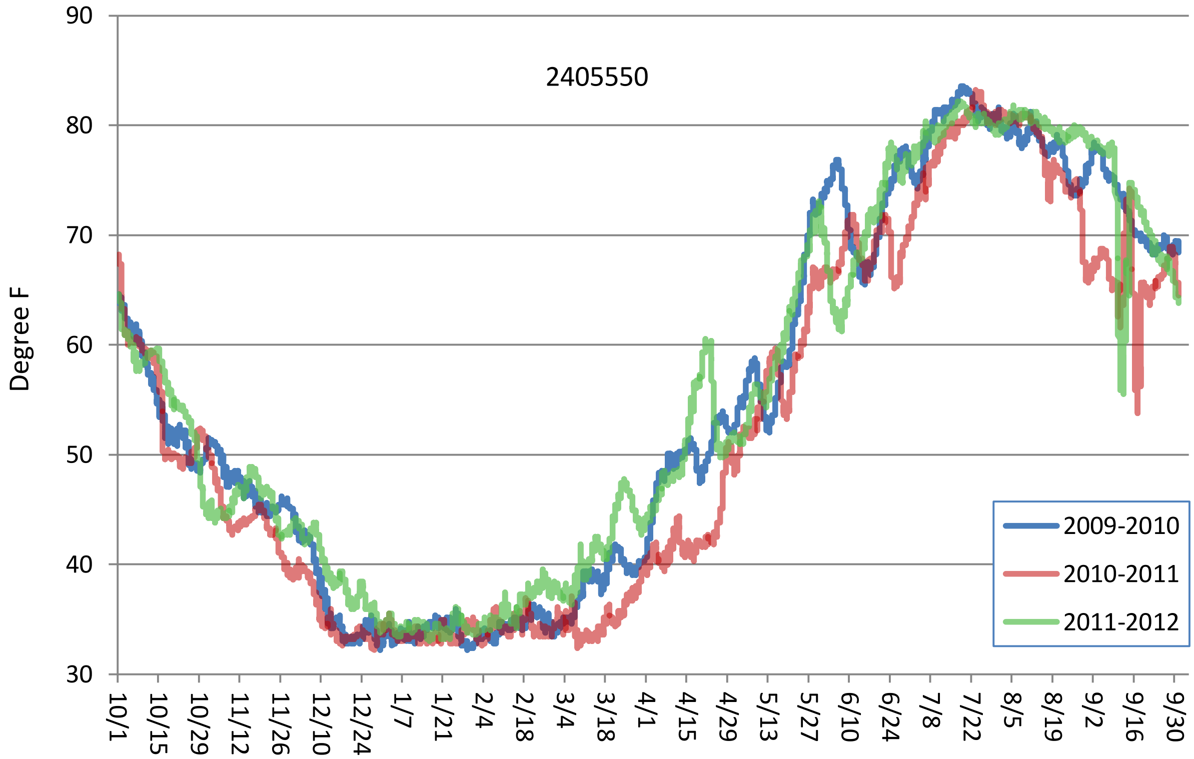

Figure 25. The Turners Falls Canal, "new" Gatehouse Fishway entrance logger (2405550), water temperature profiles for Fall 2009 through Fall 2012. Canal outage (dewatering) is evidenced in this figure with expected wide ranging data fluctuations that occur with an exposed logger, each occurrence is for a one week period of time in only 2011 and 2012.

Cabot Power Station, tailrace, Montague, MA (2405549)

The Cabot Station tailrace logger (2405549), at river mile 120, was first deployed on October 1, 2009, and was checked again on October 4, 2010, when it was downloaded and re-deployed. It was next checked on October 17, 2011, when it was downloaded and re-deployed. The logger was visited on December 4, 2012, when it was checked for accuracy, downloaded, and re-deployed. Figure 26 illustrates the temperature regimes at this site from the Fall of 2009 through the Fall of 2012.

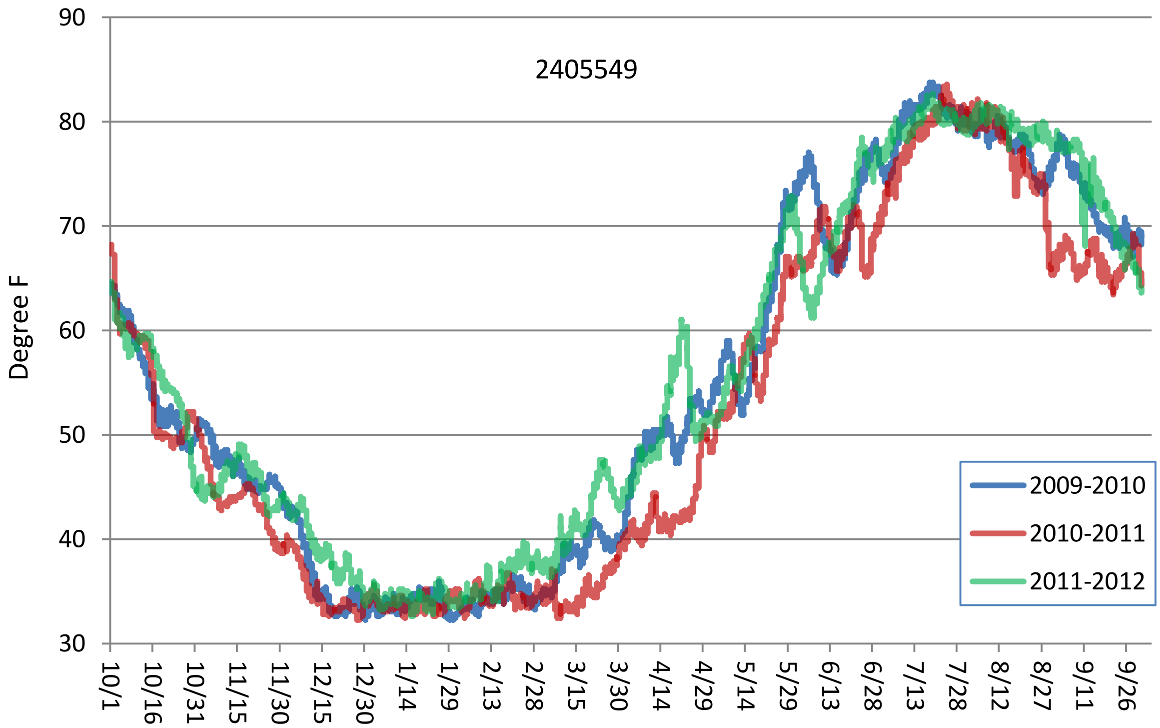

Figure 26. The Cabot Station logger (2405549), water temperature profiles for Fall 2009 through Fall 2012.

Vermont Yankee Temperature Data and Northeast Regional Temperature Data

Vermont Yankee temperature data (reported monthly mean value by year) for the period 1974 through 2011 were examined for trend and or significant shifts in baseline conditions over time. VY Station #7 data were examined due to its location 3.5 upstream of VY. A statistically significant ($p < 0.05$) increasing trend in water temperature was detected for three months using these data for January (Figure 27), September (Figure 28), and October (Figure 29) at VY Station #7. The ANOVA results for the month of January values included an F statistic = 8.256, and P = 0.0069. The ANOVA results for the month of September values were F = 8.560 and P = 0.0061. Lastly the ANOVA results for the month of October values were F = 4.575 and P = 0.0396. The National Oceanic and Atmospheric Administration (NOAA), National Climate Data Center, compiles air temperature data for the Northeast and a plot of 12 month average temperature data for the period 1896 through 2012 (October) also indicate a clear increasing trend in air temperature over time, shown in Figure 30. The NOAA Climate Data Center announced that 2012 was the warmest year on record for the U.S. for their period of record.

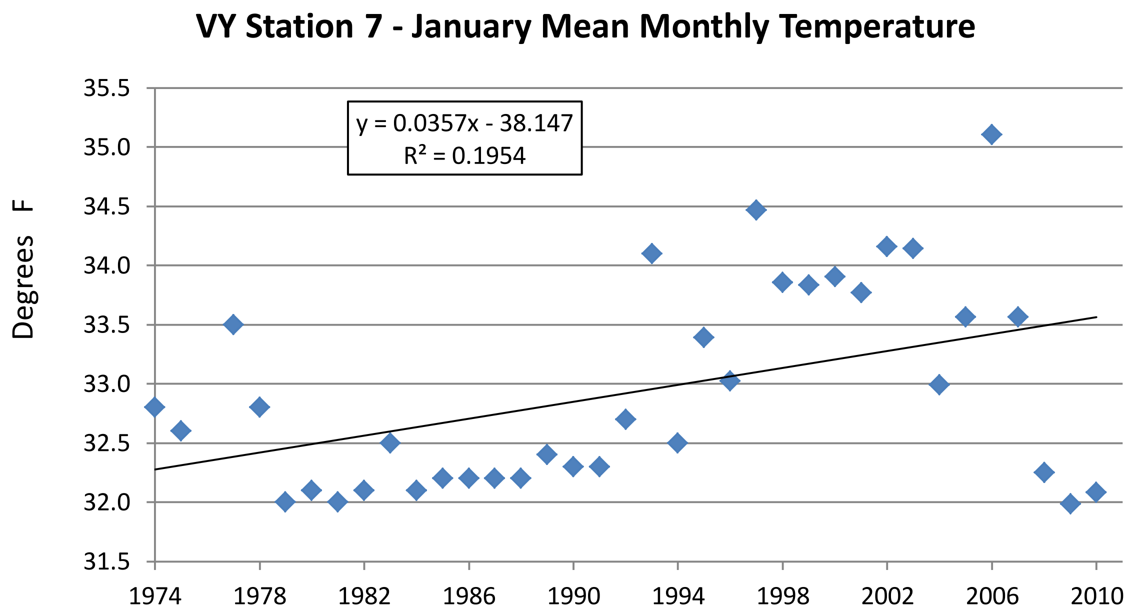

Figure 27. A plot of January's mean temperatures for Vermont Yankee's Station 7 for the period 1974 through 2011.

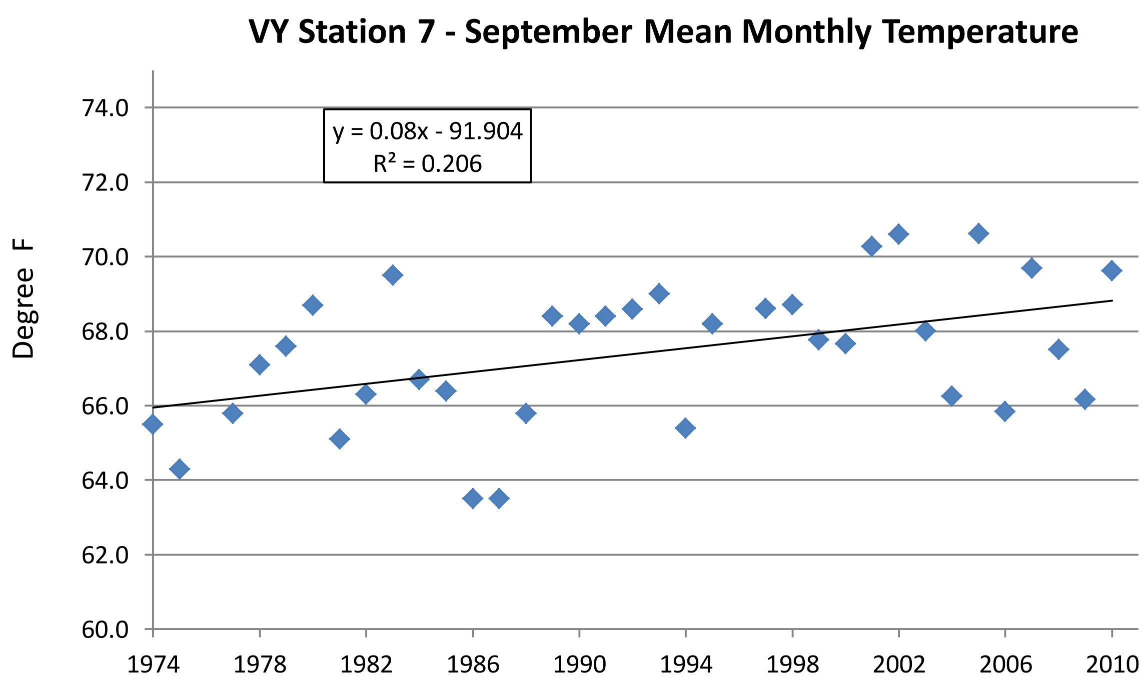

Figure 28. A plot of September's mean temperatures for Vermont Yankees' Station 7 (excludes outlier 1996 data point – very high) for the period 1974 through 2011.

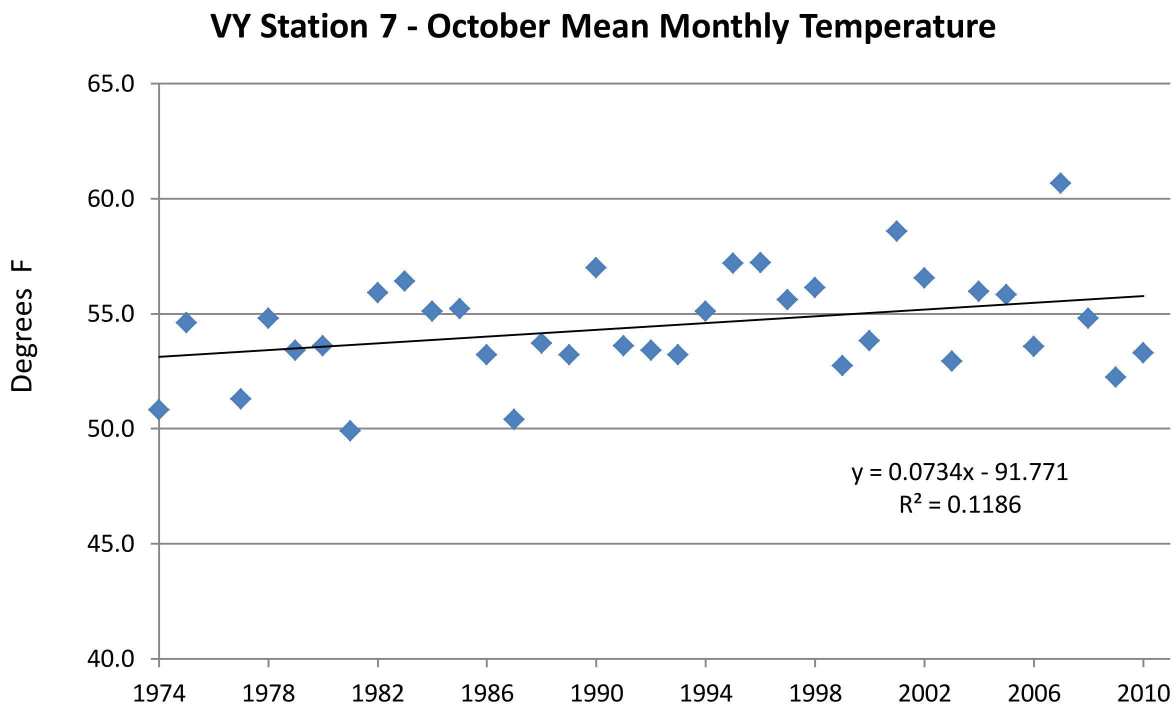

Figure 29. A plot of October's mean temperatures for Vermont Yankees' Station 7 for the period 1974 through 2011.

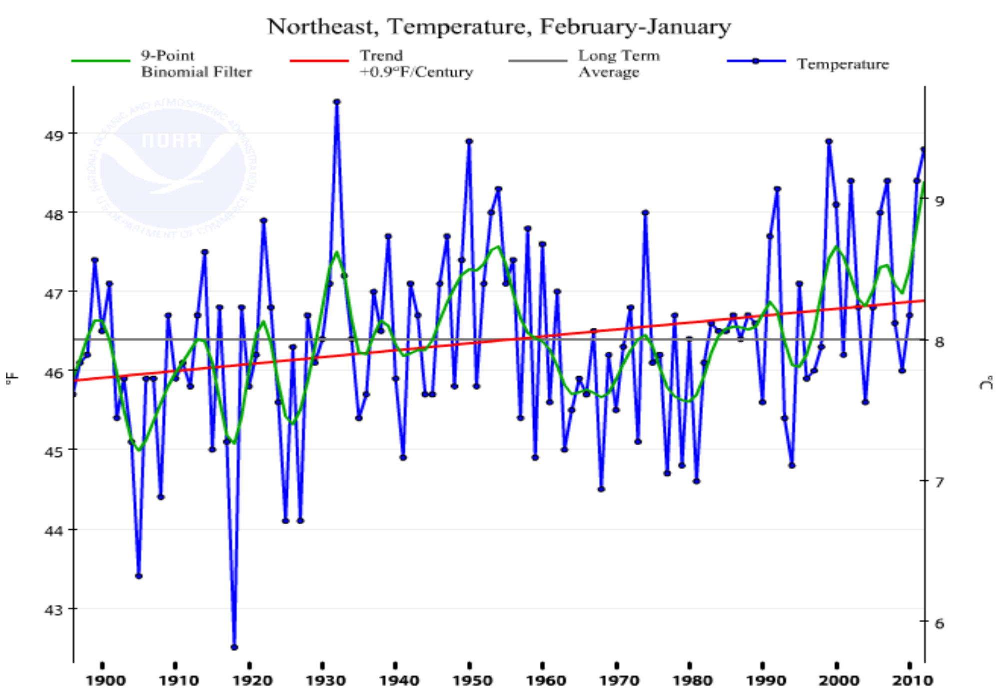

Figure 30. NOAA National Climate Data Center, Northeast 12-month average temperature for the period 1896 through 2012 (October).

Comparison of Vermont Yankee Data – upstream and downstream of VY discharge

Data for VY fish ladder temperature logger is shown in Figure 31 in comparison to VY Station 7 data for 2010 (available data), which as noted earlier includes a portion of the VY outage period (April 27, 2010 through May 21-22, 2010).

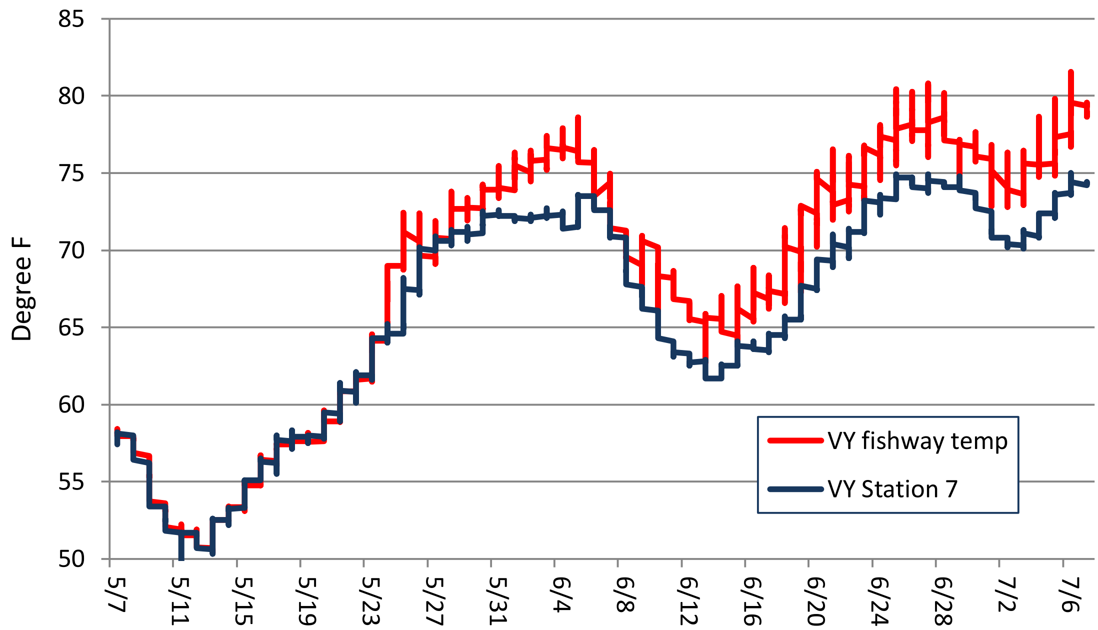

Figure 31. Vermont Yankee data for Vernon dam fish ladder compared with VY Station 7 logger data. Note that VY was offline from April 27, 2010 through May 21-22, 2010.

Discussion

One objective of the study was to document river water temperatures regimes on a full year basis where limited or no data exists. This report examined a subset of temperature loggers from the larger effort initiated in the Fall of 2009. Site selection in some cases proved to be too challenging, relative to conditions that can break anchor systems with ice, ice flows, high river flows, water velocity, debris, and sediment movement, and resulted in the loss of some loggers over time (Appendix 1). However, a large proportion of loggers remained at their deployment locations and provided data on river water temperatures that were not available from any other sources. These data represent temperature conditions that may be influenced by many factors including, but not limited to their deployment location (e.g., depth, surrounding river flow/currents), dam impoundment effects, water level/elevation fluctuations upstream of dams, power plant thermal discharges, and operations of hydropower stations and dams (e.g., peaking operations, spill). All of these factors interact in a dynamic manner to influence water temperature data at the respective sites, as they also would at other locations for other studies or monitoring programs. Water temperature data from Vermont Yankee were also examined in this report to determine the level of agreement from proximally located USFWS loggers and whether there have been any significant changes in water temperature over time outside of VY's discharge influence. The consistency of location, the relationship of observed data with data from upstream and downstream locations, data obtained upstream and downstream of the VY discharge, comparisons to other sets of data where and when available, all provide support for the use of these data in better understanding water temperature regimes in the deployment sites for a full year over a fairly broad geographic range of the main stem river. The temperature data have management implications for many organism including, but not limited to, diadromous fishes (e.g., American shad), a suite of species that for both adult and juvenile life stages are moving and migrating both upstream and downstream in this dynamic environment and utilizing available habitats, from March through late December for a range of important life history activities (Greene et al. 2009; Appendix 2 – 2012 CRASC Annual Fish Passage Notification Letter).

Water temperature profiles for USFWS loggers demonstrate substantial annual variability among as few as three years of monitoring. As noted earlier water temperature can have multiple and varied effects on biological cues, life history events, and biological metrics (e.g., energetics, survival) of fishes. It is evident from the USFWS logger temperature profile figures that Fall 2009 and Fall 2010 profiles tracked similarly at the five most upstream locations (USFWS 2405542 to 2405561). However, at site USFWS 2405562 (first site downstream of VY discharge) this consistency is decoupled, with wide ranging and elevated temperature values during these two Fall time periods. This observation is further documented by downstream logger locations, VY fish ladder logger and VY Station 3 logger (as shown in Results section). In addition, the Winter of 2009/2010 and 2010/2011 show a very similar start time frame of near freezing temperatures in mid-December, for the five most upstream USFWS logger sites, and, as noted in Results, Station 7 data closely tracks USFWS 2405561 for the period of overlapping records ($r = 0.99946$, $P < 0.0001$). However, again at site USFWS 2405562 temperatures during these same late Fall and Winter months are substantial elevated in comparison and are reasoned to be attributed to the increased "Winter period" VY thermal discharge. A consistently protracted time frame for temperature declines was observed in Fall 2011, and is apparent on the USFWS figures where temperature trend lines in USFWS figures show an approximate one month delay (compared to December 2009 and 2010) in reaching the minimum values. This was consistently observed among the five most upstream USFWS sites.

It is unknown how juvenile American shad upstream and downstream of Vernon Dam are affected by the elevated water temperatures from both the VY discharge and the dam impoundment, particularly in the Fall. In particular, questions need to be answered on whether juvenile outmigrants are affected behaviorally (e.g., delay) and physiologically, when encountering the discharge plume as normal river temperatures are declining in the Fall and VY's Winter thermal limits are permitted. Research on juvenile shad outmigration over a three period at Holyoke Dam, found decreasing water temperature determined the time migration began and ended. O'Leary and Kynard (1986) found the juvenile shad outmigration began at 19°C (66.2°F), peaked at 14-9°C (57.2°F – 48.2°F) and ended at 10-8°C (50°F – 46.4°F) Research on juvenile shad has shown impacts on behavior relative to exposure to rapidly elevated temperatures and on survival if delayed (Moss 1970; Zydlewski et al. 2003). Moss (1970) experimentally showed a significant change in juvenile American shad distribution to areas away from water heated 4.5°C (8°F) above ambient and potentially even lower amounts although noted "*smaller increases in temperature are not as easily interpreted*." The concern of a temperature shift includes the VY Summer thermal limits period but are heightened by a potential 6.7 fold increase, (if at 2°F to 13.4°F) with the shift to VY Winter thermal limits, starting October 15, during the juvenile outmigration period. Importantly, this potential 6.7 fold increase does not accurately reflect the extent or magnitude of actual temperature change that one can expect to occur from the VY discharge and the Vernon Dam downstream fishways, to the compliance monitoring site VY Station #3, where the thermal discharge is considered first fully mixed, located 0.6 miles downstream of Vernon Dam.

The USFWS logger 2405543, in the Vernon Dam tailrace, shows readings consistent with USFWS 2405562 (in the Vernon Dam impoundment below VY discharge) for both the Fall and Winter months with much higher variability observed in the impoundment, in period of time when the river should cooling (refer to Results figures for upstream sites). The VY Vernon Dam fish ladder temperature data were statistically correlated with USFWS logger 2405543, for the period of overlapping records, with Figures 15 and 16 visually demonstrating that correlation. The USFWS 2405543 data were also shown to be statistically correlated with VY Station #3 data (0.6 miles below dam) for the period of overlapping records. The USFWS 2405543 tailrace logger may not reflect the variability of water temperature in the tailrace area. The USFWS tailrace logger is in an area where VY data has shown their thermal plume to not be fully mixed under all conditions (Aquatec 1977). This important area (relative to upstream migrating fishes) where thermal discharge mixing occurs under highly variable hydro power operational conditions, could lead to wider ranging temperature values in the Vernon Dam tailrace pool, especially in lower flows when impounding and peaking generation operations occur, in any season. One cannot assume thermal mixing (via turbine discharge of VY discharge and elevated water temperatures from the impoundment) is instantaneous across time and space in all areas of the tailrace pool, at all times, and under all conditions. This situation is an artifact of pulsing of impounded water due to Vernon Dam operations as a peaking facility under its current operational license with a required minimum flow of 1,250 CFS.

Vernon Dam's power station may increase river discharge in the tailrace from the 1,250 CFS minimum flow to over 17,000 CFS at full turbine discharge in low flow conditions depending on variable river conditions. How the increase in VY elevated water temperature from the impoundment upstream of Vernon Dam subsequently influences water temperatures below Vernon Dam in relation to where upstream migrating fishes are located and in relation to the location of the Vernon Dam fish ladder's entrance, is unknown. Low river discharge levels have Vernon Station generation starting in mid-morning, with impoundment of water overnight (electricity value is at its lowest), allowing the Vernon Station tailrace water the opportunity to cool overnight. This observation on night impounding was stated in VY's 1977 report on the Vernon Station operations (Aquatec 1977). The operational scenario of impounding and later discharging in a peaking operation, is shown by 2013 river discharge data from the U.S. Geological Survey's North Walpole, New Hampshire, Gauge Station (Appendix 3), downstream of Bellows Falls Dam, that is coordinated in operations with Vernon Dam operations (same owner/operator). There are no discharge data available for Vernon Dam. Upstream passage at Vernon Dam commenced with adult shad passing on May 8, 2013, and by May 15, 2013, over 4,600 shad had passed, during VY's Winter thermal limits and these pulsing discharge flows.

Heated water discharge and water temperature mixing in the Vernon Dam tailrace pool have not been fully examined (all fish passage seasons for full periods) since the installation of the downstream fishways at Vernon Dam and the more recent turbine replacements and operational changes at Vernon Dam power station in 2008. The VY 316A Study Report, for the most recent thermal increase states, "*mixing characteristics below the dam have not been investigated since the downstream passage flow releases were implemented*" (Normandeau 2003). It is has not been determined across a full year under a full range of environmental (temperatures and flows) and operational conditions (Vernon Station and VY), actually what occurs on this topic and how it may affect migrating shad in this area. Concerns on this relate to their various energetic states of decline, river positioning, behavior, etc., as may have been experienced by the shad attempting to migrate upstream in May of 2013 in the low flow period noted.

The early Spring season is described by temperature conditions (consistent increasing trend reaching 40°F) that are shown to be variable at times over the three year period. The five most upstream USFWS logger sites for spring 2010 show a Spring start, with temperatures beginning to climb to 40°F in early to mid-March (again consistently observed among sites). The following Spring of 2011 shows a relatively late spring start, with water temperatures first reaching 40°F in early to mid-April 2011. As an estimated measured delay, the difference is approximately one month later, among the five upstream sites between these two years. The Spring of 2012 demonstrates the earliest start of spring conditions of the data, which also happens to follow the latest onset of Winter conditions. This situation created a relatively brief Winter period condition evident in the USFWS figures for the five most upriver USFWS sites in 2011 and 2012. As presented, the USFWS loggers located downstream of VY thermal discharge show wide ranging elevated temperatures through these three full-year time periods. The five most upstream USFWS logger sites, as shown in their water temperature profile figures, demonstrate a similarity in increasing and decreasing temperature periods, upstream of the VY discharge influence.

The USFWS data presented in this report show elevated water temperatures during the Winter months, downstream of VY, which remains through the Turners Falls, Cabot Station tailrace logger, an area adjacent to shortnose sturgeon spawning habitat. As noted in Aquatec (1977), because Winter has a high disparity between air and discharge water temperatures and the subsequently heated river water, this would be a "best case" scenario for maximal heat loss, but the temperature data indicates that heat loss is not enough to overcome elevated temperatures at a distance of over 23 miles from VY for the observed conditions. This information may have population implications for the federally and state endangered shortnose sturgeon population downstream of Turners Falls Dam. Researchers Kieffer and Kynard (2012) studied this shortnose sturgeon population, including movements and spawning from 1994 to 2005, and reported the only "*failed migration*" for spawning occurred in April 2002, "*Evaluations of temperature and discharge levels during the 10 months prior to the failed 2002 migration showed fish were exposed to unusual river conditions that may have affected their energy resources….Temperatures from mid-Summer 2001 until spring 2002 were higher than in all other years.*" The potential impacts of elevated water temperatures on shortnose sturgeon including but not limited to energetics and spawning migration, deserves further investigation.

Comparative examinations of USFWS temperature data and proximal Vermont Yankee temperature data, for available data, were made although logger sites were in different locations. Vermont Yankee's data for Station #7 (3.5 upstream of VY), when it was paired and plotted against the USFWS logger in closest proximity (2405561), 2.2 miles upstream of VY, demonstrated a high level of statistical correlation (Pearson correlation coefficient value $r = 0.9995$, $P < 0.0001$). The USFWS 2405561 logger was not paired at the same location and the equipment is not identical. The USFWS logger shows slightly higher temperature reads, which become more pronounced in the late spring, but are consistent and overlapping with VY measures (Figure 11).

USFWS and VY temperature data for proximally located sites, were all highly correlation (all Pearson correlation coefficient r values > 0.99), both among sites and between years. The comparison of VY Vernon Dam fish ladder temperature logger data to USFWS Vernon tailrace logger (2405543) for two seasons were highly correlated, Pearson correlation coefficient $r = 0.993$ and $r = 0.997$. The VY Vernon Dam fish ladder logger is located within the fishway proper, which is designed to provide motivated fish with an egress route to the Vernon Dam impoundment, upstream of the dam, not an area where fish are intended or expected to linger outside of daylight hours. Alternatively, the USFWS logger in the Vernon Dam tailrace is located in an area where American shad have been documented to remain for relatively long periods of time (median time 9.9 days, based on results of a radio telemetry study; Castro-Santos 2011). In addition the shad passed upstream of Turners Falls Dam were shown to make rapid and direct movement to the Vernon Dam tailrace area, most arriving within two days (median transit time 1.6 days, Castro-Santos 2011), placing them in the area of greatest influence and exposure to VY thermal discharge compared with more downstream locations. In 2012, the Vernon Dam fish ladder was repaired before that spring run and adult shad passage numbers, relative to what was counted as passing upstream of Turners Falls Dam were substantially improved from 2011. This fish ladder repair would be expected to likely change the length of time shad spent below the dam that was observed in 2011. However, the questions of the timing, magnitude, duration of fish exposure to the thermal discharge and elevated water temperatures and its effects (e.g., energetics, gonad development, passage performance, premature cessation of upstream movement) on these fish remain unanswered even with a functioning fish ladder and regardless of observed passage count data.

Fish passage is affected by many factors, including fishway operations, dam operations, river and facility discharge, and water temperature. The percentage of shad passed at Vernon Dam relative to those passed upstream of Turners Falls Dam has varied over time, from 66.9% (standard deviation 30.0), mean for period 1991-2004, declined to 3.2% (standard deviation 3.1), mean for period 2005-2011, and was 38.9% for 2012 (post fish ladder repairs). In 2013, the number passed at Vernon had increased to 18,201 shad or 51.8% of the number of shad reported as passing upstream of Turners Falls Dam. Some notes on these rates include identified issues with the fish ladder function and operation that resulted in repairs by the power company in the early run shad of 2005 and 2006, (VT agency staff identified) and most recently in preseason of 2012. Starting in spring of 2012 a more rigorous, structured annual review (USFWS Fish Passage Engineering group) of this fish ladder and downstream fishways, was instituted by the USFWS, state agencies, and the respective power companies.

Any examination of shad passage count data would need to consider the tailrace and fishway entrance area, as transit time by fish through the ladder to the point where the actual count is made, is half the way up the ladder and only a part of the fish passage process itself (e.g., ladder attraction and entry attempts). Subsequently, shad fallback, delay, cessation of movement, or performance (e.g., physiological, energetics) or entry attempts to the ladder, cannot be determined in relation to water temperature and how shad passage (counts) change within day, and at those many varied points leading up to the Vernon ladder counting window, without specialized field and laboratory studies. How rapidly shad energetics, gonad development, etc. are accelerated potentially by the increased water temperatures in the tailrace are a mechanism for this concern and potential resultant losses in fish passing upstream as a consequence, particularly "later" in the run.

Any examination of temperature effects using historic shad upstream fishway count data and water temperature is equally problematic. This approach would require a fundamental assumption of constant conditions at both the main stem fishways (efficiencies) from year to year and within year and also with environmental conditions (within year) that would be subject to repeated violation, due to the ongoing fishway changes noted earlier, and the highly variable nature of river discharge (flow) and water temperatures (within year). The environmental variability effects on fish passage are not instantaneous and equally applied over the course of the run (timing) nor from one dam's fishways to the next preceding upstream one, there is inherent variability (temporal and spatial) that cannot be dismissed. Lastly, the VY thermal discharge is present in recent decades shad count data and thus only an observed response with the effect in question can be described with such an examination.

Any potential effect(s) of elevated temperatures are not expected to manifest themselves at a constant rate across a full range of values. Threshold temperature values that define important life history events, such as spawning, translate to the onset and cessation of these events, with the term "peaking" often noted in the literature, likely reflective of an "optimal" sub-range that may vary based on other factors. For example, a temperature range of biological significance for American shad spawning has been reported between 57.2°F – 68.0°F (Stier and Crance 1985). American shad spawning research in the Connecticut River reported peak spawning at 22°C (71.6°F) in 1967 and at 14.4°C (58°F) in 1968 (Marcy 1976). The same study further noted that the lower mean temperature of May 1967 (mean 11°C; 51.8°F) may have delayed gonad maturation and the fish may have migrated farther upstream than in 1968 (mean 15°C; 59°F). Marcy (1976) states, "*Differences in time and place of spawning between 1967 and 1968 may have been caused by difference in temperature*." Layzer (1974) studied spawning American shad upstream of Holyoke Dam in 1972, and determined "*most of the shad eggs were collected when river temperatures were between 16.5°C* (61.7°F) *and 19.0°C* (66.2°F)." Subsequent American shad spawning research determined peak spawning downstream of Turners Falls Dam, occurred prior to water temperatures reaching 21°C (69.8°F) (Kuzmeskus 1977). Water temperature as a variable, is consistently noted in most studies to be confounded by river discharge, which may be dynamic in the spring. As noted by Leggett et al. (2004), "*discharge and temperature in the Connecticut River tend to be inversely correlated during the time of the adult shad migration into freshwater.*"

There are several published studies on water temperature effects on American shad migration, movement, and energetics that are specific to the Connecticut River American shad population. As stated by Glebe and Leggett (1981), "*Overall adult mortality is also positively correlated to the thermal regime of the river during the migration, being higher in years when the water* *temperature during the migration is higher than average*." In their 1999 study on Connecticut River American shad metabolic rates, Leonard et al (1999) states "*temperature had a significant effect on metabolic rate*" and provided the study results. Another American shad study by Leonard and McCormick (1999) also on the Connecticut River, places this finding in an important management context as "*energy availability has the potential to be a limiting factor in migration, particularly in those species that do not feed…*" Their results suggested "*there are large year-to-year differences affecting energy expenditures…*" and concluded "*clearly, upstream anadromous migration is energetically expensive for American shad…they are probably not energetically exhausted at the end of their current maximum migratory distance in the Connecticut River, since 40% energy depletion is common but 60% depletion is possible*." Their study was conducted in 1993 and 1994 and thus characterized the conditions experienced by those fish in those specific years, prior to subsequent VY temperature discharge increases. Leggett et al. (2004), stated that "*in any given year, either discharge or temperature could be the dominant determinant of energy expenditure per kilometer*."

Temperature data detailed in this report lead to some important fish management, restoration and recovery questions. For example, what areas of the river do migratory fishes seek out, find themselves in, move through, and or are attracted/repelled by, as they explore or determine routes to either move up or downstream of the Vernon Dam? What are the consequences of shad being exposed to elevated water temperatures during both upstream and downstream migrations, such as potential accelerated gonad maturation, accelerated cessation of upstream movement, and accelerated loss of energetic reserves for survival on out-migration. What if any passage delays are occurring and what environmental conditions may influence delays and motivation (energetics or physiology) for movement and route selection to up and downstream fishways or performance in successfully using those fishways? For fish that are not able to pass up or downstream for any number of factors (such as flow and temperature likely working interactively but varying in extent and contribution through time), how do they utilize the habitats they may concentrate in, such as the tailrace or in the area upstream of the dam in the forebay area of Vernon Station, and how are behavior, movement, and survival affected by elevated temperatures, including exposures potentially beginning at Holyoke Dam? What are the outcomes or consequences of these scenarios in terms of energetic costs, gonad development, sex ratios, motivation or persistence to continue their migration both upstream and downstream, fish passage performance, and the likelihood to survive outmigration for both juveniles and post-spawn adults?

As discussed earlier, a concern on the VY thermal discharge plume and subsequent elevated water temperatures includes the close proximity of the Vernon Dam. Currently, the Vernon Dam fishways operational schedule for diadromous fishes, required through law by the Federal Energy Regulatory Commission, does not correspond with the permitted thermal discharge schedule of VY (Table 4). The State and Federal fish and wildlife agencies have legal authority to require the installation and operation of up and downstream fishways or passage measures, which have not been applied to the VY thermal discharge periods. Studies that have been requested by the VY Environmental Advisory Committee as well as the Connecticut River Atlantic Salmon Commission to answer specific questions on potential impacts to species such as American shad, have yet to be conducted (CRASC letter to VTANR, 2005).

Table 4. Vernon Dam up and downstream fishway operation schedule (2012) from the Connecticut River Atlantic Salmon Commission and Vermont Yankee thermal discharge permit periods.

Species	Vernon Dam Fish Passage	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
American shad / blueback herring adults	Up												
American shad / blueback herring adults	Down												
American shad / blueback herring juveniles	Down												
Atlantic salmon smolts	Down												
Atlantic salmon adults	Up												
Atlantic salmon adults	Down												
American eel	Down												
<u>VY Discharge</u> (13.4 °F increase permitted)													
<u>VY Discharge</u> (2 - 5 °F increase permitted)													

Compliance for permitted/estimated whole river temperature increase is partially determined 0.6 rm downstream (VY Station 3) of Vernon Dam and by VY Station 7 (using an equation to determine compliance) that is located 3.5 miles upstream of VY. Vernon Dam and its fishways are located between the only two VY temperature monitoring stations and is 0.45 miles downstream of the VY discharge point.

The Connecticut River Atlantic Salmon Commission, American Shad Management Plan (1992) goal is to "*restore and maintain a spawning shad population to its historic range in the Connecticut River basin and to provide and maintain sport and in-river commercial fisheries for the species*[A]." This plan also identifies the following objectives:

- Achieve and sustain an adult population of 1.5 to 2.0 million individuals entering the mouth of the Connecticut River annually;
- Achieve annual passage of 40% to 60% of the spawning run (based on a 5-year running average) at each successive upstream barrier on the Connecticut River main stem; and
- Maximize outmigrant survival for juvenile and spent adult shad
  ([A] historic upstream range extent is Bellow Falls, VT)

Based on this existing plan, a target upstream passage number of adult shad ranges from 96,000 up to 432,000 fish, upstream of Vernon Dam, without an adjustment for losses from in-river fisheries. Use of the full historic range in the main stem river (Vernon to Bellows Falls most upstream segmented reach) will help provide population resilience and buffer against potential catastrophic or other negative impacts to juvenile shad production that may occur in the lower main stem from any number of environmental, anthropogenic or other sources and events. Since the Vernon Dam fish ladder opening in 1981 through 2012 an average of 5,266 shad passed annually upstream of Vernon Dam; the maximum number passed was 37,200 fish, in 1992. This includes several time periods of poor passage that were effectively addressed in both 1989 and in early 2012. Other than the observable periods of poor passage, based solely on counts, rates are viewed as fairly good, with important studies on passage efficiency planned as part of the current FERC relicensing process.

As with all fishways, many factors have influenced passage rates, passage numbers, and efficiencies through time, not the least of which have been substantial changes at all fish ladders, lifts, and dams (operations/facilities). Modifications and repairs to fishways and dams both structurally and operationally over the history of the anadromous fish restoration program, with agency input and the cooperation or licensing of the various hydropower owner/operators, has resulted in increased fish access to previously blocked habitats and ongoing passage improvements (e.g., downstream fishways and guidance measures). Environmental variations of river flow and temperature and variables such as dam spill frequency, magnitude, and timing add more complexity within and among years, complicating any examination of mean annual values of passage or other summarized rates. With the current Federal Energy Regulatory Commission's relicensing process underway for both Turners Falls Dam and Vernon Dam (new licenses due in 2018), additional significant improvements to up and downstream passage at these facilities are anticipated by the state and federal resource agencies that are engaged in this process. Fish passage technology and future fishway performance is far from static, rather it is highly dynamic and new insights are obtained through study and application.

For American shad in the Connecticut River, in-river fishing mortality is variable year to year, but in recent years (1996 – 2009), due to a variety of factors, fishing mortality has been relatively low, with reported instantaneous total fishing mortality values of < 0.1 (CTDEEP 2010). This loss to fishing mortality, as represented in terms of a percentage loss from the total available population, has ranged from 3.6% to 7.4% over this time period. Due to more restrictive harvest management measures required by ASMFC (2010), these levels are expected to remain low into the future, as required for ASMFC federal compliance. This is expected to aid in Connecticut River restoration objectives. These restrictive measures were developed as the ASMFC, American Shad Stock Assessment Subcommittee Report (2007) found that "*stocks were at all-time lows and did not appear to be recovering at acceptable levels*." It identified the primary causes for the continued stock declines as a combination of excessive mortality, habitat loss and degradation, and migration and habitat access impediments. A subsequently released ASMFC Shad Plan provided more details and insight into potential conservation measures of relevance.

The Atlantic States Marine Fisheries Commission Amendment # 3 to the Interstate Fishery Management Plan for Shad and River Herring (American Shad Management) approved in 2010, identifies the goal to "*Protect, enhance, and restore Atlantic coast migratory stocks and critical habitat of American shad in order to achieve levels of spawning stock biomass that are sustainable, can produce a harvestable surplus, and are robust enough to withstand unforeseen threats*." This Plan also identifies the following objectives: Maximize the number of juvenile recruits emigrating from freshwater stock complexes; and restore and maintain spawning stock biomass and age structure to achieve maximum juvenile recruitment. This Plan provides specific Recommendations which include: Reduce the amount of thermal effluent into rivers and require a thermal zone of passage for fish migration and movement.

Dissolved gas in river water from increased thermal inputs is an area that requires examination over a full year period and under varied operational (VY and Vernon Station) and environmental conditions to determine if dissolve gas super saturation (total gas pressure) is occurring (nitrogen and oxygen), and if so, to what extent over both space and time. A substantial synthesis of this concern from an aquatic biological perspective is presented in Weitkamp and Katz (1980). The researchers provide basic facts that the capacity of water to hold dissolved gas is inversely related to temperature and increasing water temperatures will produce gas super saturation in water that is initially saturated. Impacts to fishes include gas bubble disease that in worst case result in mortality events and impacted physiology and behavior are described. The tolerance of fish species to dissolved gas super saturation is not the same at all life stages or among species (Weitkamp and Katz 1980). The researchers' state, "…*super saturation should be considered any time aquatic organisms may be exposed to heated water. This includes cooling waters of large industrial facilities*…" This is an area that requires attention for potential aquatic biota impacts.

Management Recommendations

The current scope and intensity of VY year-round water temperature monitoring (2 stations, only one is downstream of VY) is limited and not sufficient to adequately describe and monitor thermal conditions of the permitted discharge when migratory fish are present (as defined by required fish passage dates of operation at the adjacent Vernon Dam) or to examine potential concerns further downriver (e.g. shortnose sturgeon overwintering). More temperature monitoring stations, recording actual water temperatures at sub-hourly frequency at a range of depths, should be developed and maintained. These monitoring sites should include: 1) point of discharge from plant; 2) locations downstream of the plant in areas that should be defined by zones of fish passage, particularly along western side of river into the Vernon Dam forebay (area where up and downstream fishways – exits and entrances, respectively are located); 3) tailwater of Vernon Dam in area upstream of Station 3 (area where upstream migrating fish have been delayed, tailrace area); and 4) in areas downstream of Station 3. Exact locations should be determined in consultation with the fishery resource agencies.

It is unknown how adult shad migrating upstream, after having to pass three fishways at two preceding main stem dams, and nearing the upstream extent of their migration, are affected (e.g., energetics, physiology, behavior, passage performance, reproductive status) by elevated water temperature exposure from the current VY permitted thermal discharge, under current dam and hydroelectric station operations, particularly in the context of variability in run timing, duration and magnitude from year to year and within year (e.g., Spring 2012 and 2013 adult shad run timing). Studies designed to assess potential impacts from elevated water temperatures should be conducted, including but not limited to physiology, energetics, fish passage performance, survival, premature cessation of upstream migration, advancement of gonad development, and shifts in behavior or movement (Leonard et al. 1999; Leggett 2004; Leggett et al. 2004; Castro-Santos and Letcher 2010). As stated in a Vermont Yankee report, "…*if the fishway is near the Vermont shore, the plume would have to be negotiated by the fish if they remain near the surface*" (Aquatec 1977). That report precedes the Vernon Dam fish ladder and downstream bypass installations (that are surface orientated designs) but accurately notes the concern that has since evolved into additional components of migration concern detailed in this report. Spent (post spawn) shad, upstream of Vernon Dam, also may be subjected to elevated water temperatures from the VY discharge and its potential effects on fish behavior, movement, physiology, energetics, and survival coupled with synergistic effects of potential delays at the dam if surviving to pass back downstream (Glebe and Leggett 1981; Leggett et al. 2004; Castro-Santos and Letcher 2010).

The current temperature model utilized to determine VY water temperature compliance was developed prior to significant facility and operational changes at Vernon Dam Station. In 2008, the operational turbine capacity at Vernon Station was increased from 11,000 CFS to 17,300 CFS, or a 54% increase. As a result, operational changes for the Vernon Station were developed based on the new units and performance parameters, including changes on triggers/frequency of required spill. In addition, this paper has shown statistically significant increases in mean monthly water temperatures that have occurred over time with VY's upstream monitoring long-term data. The impact of these alterations to the thermodynamics model and actual temperature regimes should be re-examined using the new conditions and the more recent highly dynamic and variable river conditions.

The VY temperature compliance model for the most recent variance application states that "worst case" scenario data were collected and used in model development based upon low Summer flows and warmest seasonal temperatures, an artifact of water quality compliance concerns alone. In fact, worst case scenarios can occur throughout the year relative to diadromous fishes due to the placement of the VY discharge and the Vernon Dam fishways and the various species and lifestages that migrate up and downstream of this dam from April 1, through December 31 (Table 4), omitting the previous stated potential concerns for the endangered shortnose sturgeon through the Winter months. The example of spring 2013 river discharge conditions and subsequent shad passage timing mentioned earlier, highlight this concern. What are the zones of passage for these species and life-stages, what are the potential effects of current permitted discharge (including duration of exposure, timing of exposure, magnitude of exposure) on fish movements, behavior, (e.g., route selection) and related effects (e.g., gonad development, fish condition, physiology, energetics, survival)? In the absence of VY thermal discharge (VY Winter and Summer periods), what might happen to shad passage rates, shad sex ratios, and female reproductive status upstream of Holyoke Dam into Vermont and New Hampshire? In order to determine how VY's thermal discharge may affect these species, more specific information is needed, including but not limited to 1) how long (distance and time) are migrants exposed to elevated temperatures (and magnitude) and in relation to seasonal run timing, 2) how does elevated temperature exposure alter migrant energetics, physiology, reproductive status, behavior, survival, fish passage performance and subsequently fish abundance in the upper basin. These questions should be examined and tested in a scientifically rigorous manner with a control (no thermal discharge baseline) and treatment conditions (various operational and environmental treatment conditions) over sufficient time periods of study using both laboratory and field approaches, to account for the inherent range of variability in river flow, natural temperature regimes, and shad run timing.

VY data have shown significant increasing trends in river water temperatures using daily mean values by month for January, September, and October since 1974. It is unclear how both diadromous and resident fish species and populations will respond over time these changes and potentially other variables that are beyond human control. However, it is clear that dramatic declines in diadromous fishes in the north Atlantic has occurred and all threats to recovery and restoration including habitat impacts must be carefully considered and evaluated in terms of possible mitigation measures (Limberg and Waldman 2009). Vermont Yankee has the ability to operate closed cycle. This mode of operation may help to address the potential impacts of the station cooling water system to aquatic resources by 1) reducing the loss of fish eggs, larvae, and juveniles to impingement and entrainment (not discussed in this report) and 2) eliminating or reducing heated effluent discharge into the river until such time as it can be conclusively shown, through the appropriate studies, the permitted discharge is in fact not impacting fishery resources as discussed in this report.

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Appendix 1. A total of 27 temperature loggers were deployed in Fall 2009 from Old Lyme, Connecticut, to Moore Dam, Concord, Vermont.

Location Description and installation date	Lat (N)/Long(W) and depth (ft)	Logger ID	Download Fall 2010/Status	Download Fall 2011/Status	Download Fall 2012/Status
Old Lyme CT, CTDEP Marine HQ, under dock, Date: 9/22/09	41° 18. 760 N 72° 20. 770 W Tidal, 4-8' d	2405548	Yes/redeploy	Yes/redeploy	
Moodus, CT, Salmon River, Leesville Dam Ladder (exit) Date: 9/22/09	41° 31. 006 72° 28. 973 4' d	2405547	Yes/redeploy	Yes/redeploy	
Rocky Hill, CT, Ferry Crossing DOT Date: 9/22/09	41° 39.984 72° 37.779 6' d	2405546	Yes/redeploy	Yes/redeploy	
Windsor, CT, Farmington River, Rainbow fishway entrance pool Date: 9/22/09	41° 54. 911 72° 41. 586 (in passage operation) 4' d	2405545	Error in 2009 set up, time increment setting / redeployed	Yes/redeploy	
Thompsonville, CT, USGS River gauge water box Date: 11/9/09	41 59.239 72 36.327	2405580	Yes/redeploy	Yes/redeploy	
West Springfield, MA, dam power canal, behind trash rack Date: 12/16/09	42 05.583 72 38.790 6' d	2405581	Yes/redeploy	Yes/redeploy	
Holyoke, MA, dam tailrace, off railing Date: 10/2/09	42° 12. 685 72° 36. 144 6' d	2405555	Yes/redeploy	Yes/redeploy	Yes/redeploy
Holyoke, MA, in front of dam gatehouse, off railing Date: 10/2/09	42° 12. 739 72° 36. 219 Approximately 8' d	2405556	Lost	-	-
Conway, MA, Deerfield River Dam # 2, forebay, off railing adjacent to intake Date: 10/5/09	42° 34. 397 72° 42. 450 6' d	2405557	Yes/redeploy	No/buried in sediment*/lost	-
Shelburne, MA, Deerfield River Dam # 4, river right, off railing adjacent to intake gates, forebay Date: 10/5/09	42° 37. 199 72° 44. 691 6' d	2405558	Yes/redeploy	Yes/redeploy	
Montague, MA, Cabot Station, adjacent to downstream fishpassage flume, off of railing of tailrace deck Date: 10/01/09	42° 35.231 72° 34.756 6' d	2405549	Yes/redeploy	Yes/redeploy	Yes/redeploy

Montague, MA, Turners Falls Gatehouse, set in fishway new extended entrance (Canal) – note dewater canal dates Date: 10/01/09	42° 36. 635 72° 33. 241 3' d subject to canal de-watering	2405550	Yes/redeploy	Yes/redeploy	Yes/redeploy
Gill, MA, Turners Falls Pool #1; Horserace area, off large boulder Date: 10/01/09	42° 36. 130 72° 30. 276 6' d	2405551	Yes/redeploy	Yes/redeploy	Yes/redeploy
Erving, MA, Turners Falls Pool #2, just upstream of French King Rock, river left Date: 10/01/09	42° 36. 300 72° 29. 346 6' d	2405552	Yes/redeploy	Yes/redeploy	Yes/redeploy
Gill, MA, Turners Falls Pool #3, just downstream of Renaissance rock ledge, off root wad, below waterline Date: 10/01/09	42° 38.447 72° 29.128 6' d	2405553	Could not locate cable due to water level	Located/ downloaded 2009-2010 - redeployed	Yes/redeploy
Northfield, MA, Turners Falls Pool #4, river left, below Rt 10 bridge, 100ft downstream of start of bank tire stabilization Date: 10/01/09	42° 40. 934 72° 28. 148 6' d	2405554	Yes/redeploy	No/buried in sediment*/lost	-
Hinsdale, NH, Turners Falls Pool #5, ~ 0.75 miles below Ashuelot R. confluence, river left, rock ledge outcrop across from island Date: 10/21/09	42 45.785 72 28.601 7' d	2405566	Yes/redeploy	Yes/redeploy	Yes/redeploy
Hinsdale, NH, Turners Falls Pool #6, across from Stebbins Isl, river left, earthen dam face, in eddy area (low flow), off sycamore Date: 10/21/09	42 46.322 72 30.315 6' d	2405563	Yes/redeploy	Yes/redeploy	Yes/redeploy
Vernon, VT, Vernon Station/Dam, off tailrace railing, near fishway entrance and downstream fish pipe, runs continuous Date: 9/28/09	42° 46. 279 72° 30. 885 5' d	2405543	Yes/redeploy	Yes/redeploy	Yes/redeploy
Hinsdale, NH, Vernon Pool, on river left, off tree, near dam safety barrels attachment Date: 10/14/09	42 46.283 72 30.624 6' d	2405562	Yes/redeploy	Yes/redeploy	Yes/redeploy
Vernon, VT, Vernon Pool, 2.2 miles upstream of VY discharge, river right, off of exposed root Date: 10/14/09	42 48.075 72 32.130 6' d	2405561	Yes/redeploy	Yes/redeploy	Yes/redeploy

Hinsdale, NH, Vernon Pool, just upstream of RR bridge on river left, cabled downstream around large boulder Date: 10/14/09	42 50.246 72 32.711 6’ d	2405560	Yes/redeploy	Yes/redeploy	Yes/redeploy
Brattleboro, VT, Vernon Pool, on river right just upstream of Rt 9 bridge, attached to tree Date: 10/14/09	42 53.062 72 33.152 6’ d	2405559	Yes/redeploy	Yes/redeploy	Yes/redeploy
N. Walpole, NH, Bellows Falls Station, off of fishway entrance railing in tailrace Date: 9/28/09	43° 07. 982 72° 26. 489 10’ d	2405544	Yes/redeploy Subject to flume ice damage on railing	Yes / NOT redeployed	-
N. Walpole, NH, Bellow Falls Station, off railing in tailrace adjacent to fishway entrance Date: 3/9/10	Same coord.	2405567	Yes/redeploy	NO/ new unit deployed #2405583	Yes/ #2405583 redeployed
Lebanon, NH, Wilder Dam, off tailrace railing adjacent to fishway entrance on NH side Date: 9/28/09	43° 40. 054 72° 18. 237 10’ d	2405542	Yes/redeploy	No / hung up at depth	Yes / unit no longer hung up / 2010 – 2011 redeployed
Monroe, NH, Comerford Station tailrace, off vegetation in blasted rock Date: 10/27/09	44 19.448 72 00.191 6’ d	2405570	Yes/not redeployed	-	-
Littleton, NH, Moore Dam tailrace, cabled off of tailrace roof, far right side Date: 10/27/09	44 20.182 71 52.489 10’ d	2405569	Lost/not redeployed	-	-
Littleton, NH, Moore Dam, off of main dam face railing Date: 10/27/09	44 20.142 71 52.429 40’d	2405572	Lost/not redeployed	-	-
Hartford, VT, White River, adjacent to Hartford USGS gauge house Date: 10/29/09	43 42.862 72 25.093 6’ d	2405568	Lost/not redeployed	-	-

*post Tropical Irene Storm flood event

Appendix 2. Annual Fish Passage Notification Letter to main stem hydropower operators from CRASC, 2012.

2012 CT RIVER SCHEDULE OF UPSTREAM FISH PASSAGE OPERATIONS

Location (Project)	**Upstream Fish Passage**	**Species**	**Life Stage**	**Dates of Operation[1]**	**Hours of Operation**
Wilder	Ladder	salmon salmon	adult adult	May 15 - July 15 September 15 - Nov 15	24 hrs/day 24 hrs/day
Bellows Falls	Ladder	salmon salmon	adult adult	May 15 - July 15 September 15 - Nov 15	24 hrs/day 24 hrs/day
Vernon	Ladder	salmon salmon shad & herring	adult adult adult	April 15 - July 15 September 15 - Nov 15 April 15 - July 15	24 hrs/day 24 hrs/day 24 hrs/day
Turners Falls	Cabot Ladder, Gatehouse Ladder, and Spillway Ladder	salmon salmon shad & herring	adult adult adult adult	April 1 - July 15 September 15 - Nov 15 April 1 - July 15	24 hrs/day 24 hrs/day 24 hrs/day
Holyoke	Zone-of-Passage Flows[2] Tailrace Lift, and Spillway Lift Tailrace, and Spillway Eelways	salmon, shad, herring and sturgeon salmon salmon shad & herring eels	adult adult adult adults juvenile	April 1 - July 15[3] April 1 - July 15 September 15 – Nov 15 April 1 - July 15 April 15 - November 15[5]	24 hrs/day up to 12 hrs/day[4] up to 12 hrs/day[4] 24 hrs/day

1/**Actual dates of operation are based on passage of fish at the next lowest downstream fishway and/or monitoring of radio-tagged adult salmon locations.**

2/Zone -of-passage flow of 1,300 cfs or more to the bypass reach below the dam

3/Zone-of-passage flows for shortnose sturgeon passage in Summer (July 16 through September 14) are not currently required until downstream passage measures are in place to protect down-running sturgeon.

4/Actual hours of operation on a day-to-day basis are to be determined by the Massachusetts Division of Fisheries and Wildlife in consultation with the project owner.

5/Actual eelpass installation dates are dependent on river flow conditions and in consultation between project owner and MADFW and USFWS

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Appendix 2. Continued.

2012 CT RIVER SCHEDULE OF DOWNSTREAM FISH PASSAGE OPERATIONS

Location (Project)	Downstream Fish Passage Exit	Species	Life Stage	Dates of Operation	Hours of Operation
Gilman/Dalton	Interim Bypass Sluice	salmon	smolt	April 1 – June 15	24 hrs/day
Moore	Bypass Sluice and Trap	salmon	smolt	April 1 - June 15[1]	24 hrs/day
McIndoes	Log Sluice[3]	salmon	smolt	April 1 - June 15	24 hrs/day
Ryegate (Dodge Falls)	Fish Bypass Facility	salmon	smolt	April 1 - June 15	24 hrs/day
Wilder	Log Sluice[2]	salmon salmon	smolt adult	April 1 - June 15 October 15 - December 31[5]	24 hrs/day 24 hrs/day
Bellows Falls	Angled Fish Guide Wall and Log Sluice[2]	salmon salmon	smolt adult	April 1 - June 15 October 15 - December 31[5]	24 hrs/day 24 hrs/day
Vernon	Fish Bypass at Unit 10	salmon salmon shad shad eels	smolt adult adult juvenile adults	April 1 - June 15 October 15 - December 31[5] June 1 - July 31 **August 1** - November 15 September 1 – November 15	24 hrs/day 24 hrs/day 24 hrs/day 24 hrs/day 24 hrs/day
	Louvers and Fish Pipe at Unit 4	salmon salmon shad shad eels	smolt adult adult juvenile adults	April 1 - June 15 October 15 - December 31[5] June 1 - July 31 **August 1** - November 15 September 1 – November 15	24 hrs/day 24 hrs/day 24 hrs/day 24 hrs/day 24 hrs/day
Northfield	Barrier Net	salmon	smolt	April 1 - June 15[2]	24 hrs/day
Turners Falls	Log Sluice and Trash Sluice	salmon salmon shad shad eels	smolt adult adult juvenile adults	April 7 - June 15 October 15 - December 31[5] June 1 - July 31 **August 1** - November 15 September 1 – November 15	24 hrs/day 24 hrs/day 24 hrs/day 24 hrs/day 24 hrs/day
Holyoke[6]	Canal Louver Bypass	salmon salmon shad shad eels sturgeon eels	smolt adult adult juvenile adults adults adults	April 7 - June 15 October 1 - December 31[5] June 15 - July 31 **August 1** - November 15 August 1 – August 31 April 7 – November 15 September 1 – November 15	24 hrs/day 24 hrs/day 24 hrs/day 24 hrs/day 24 hrs/day 24 hrs/day 24 hrs/day
	Bascule Gate[4]	salmon salmon shad shad eels	smolt adult adult juvenile adults	April 7 - June 15 October 15 - December 31[5] June 1 - July 31 **August 1** - November 15 September 1 – November 15	24 hrs/day 24 hrs/day 24 hrs/day 24 hrs/day 24 hrs/day

1/Date of initiating operation April 1 or as soon as pond level permits operation. End date may be modified based on smolt trap collections.
2/Date of initiating operation April 1 or as soon as possible after high spring flows subside. Net can be removed after smolt emigration ceases at the Cabot sampler upon consultation with the Coordinator.
2/Minimum log sluice gate opening of 3.5 feet at Bellows Falls and 5 feet at Wilder.
3/The McIndoes log sluice gate is now capable of tracking headpond level and can operate continuously.
4/Bascule gate may be closed periodically in order to facilitate upstream passage at spillway fishlift, as directed by Massachusetts Division of Fisheries and Wildlife fishway personnel.
5/Downstream passage operation, or monitoring with operation as needed, is required for salmon when salmon are upstream of a location.
6/Holyoke passage operation dates may be adjusted to facilitate fish passage facility improvements if approved by the Massachusetts Division of Fisheries and Wildlife and U.S. Fish and Wildlife Service.

Appendix 3. U. S. Geological Survey's North Walpole, NH, gauge station data for the spring of 2013, illustrating impounding and generation cycling of water from the TransCanada Bellows Falls Station, upstream of VY and TransCanada Vernon Dam/Station.